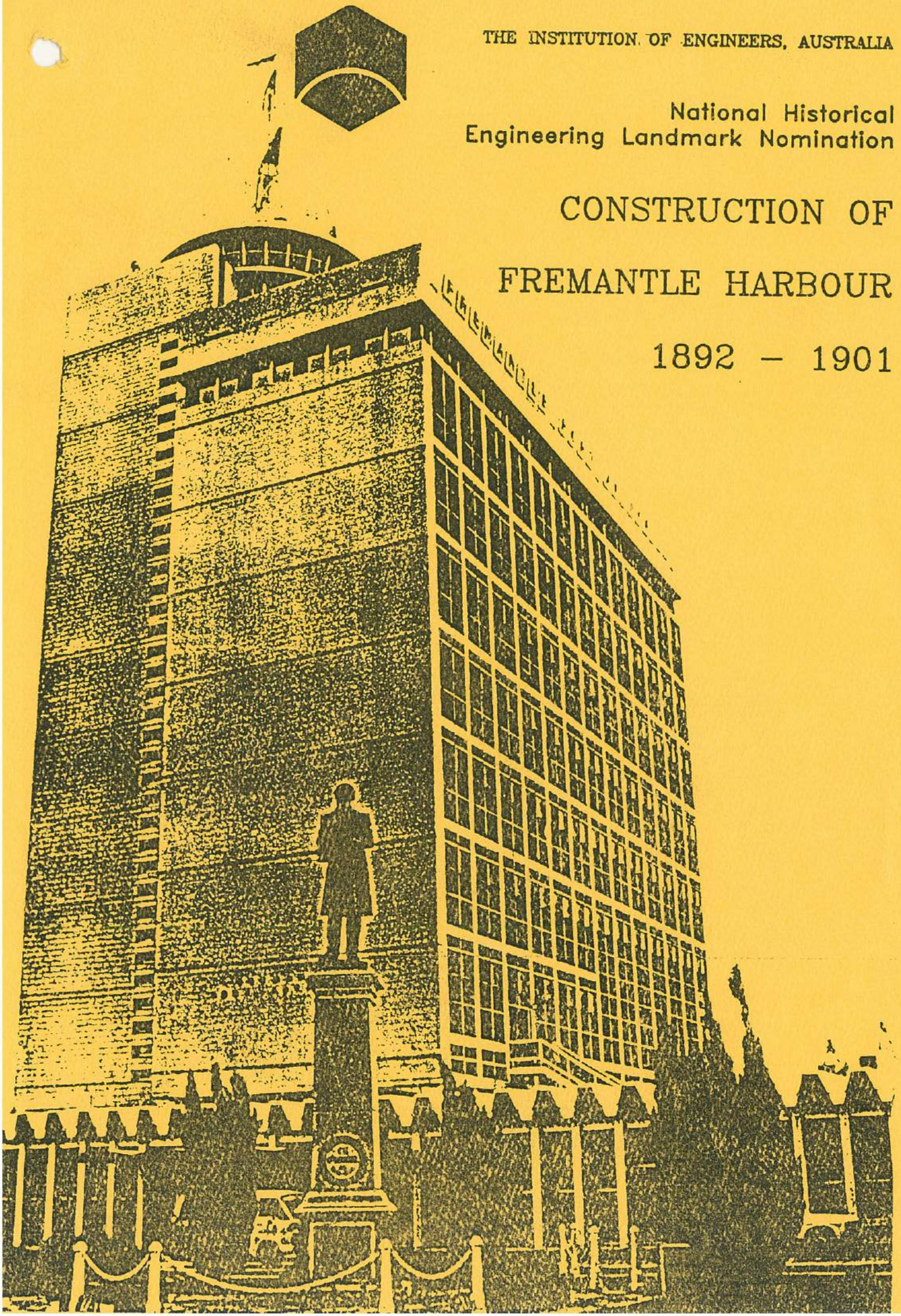
THE INSTITUTION OF ENGINEERS, AUSTRALIA

National Historical
Engineering Landmark Nomination

CONSTRUCTION OF FREMANTLE HARBOUR 1892 – 1901



NATIONAL HISTORIC ENGINEERING LANDMARK

Nomination Form

National Engineering
Heritage Panel
The Institution of Engineers, Australia
11 National Circuit
BARTON ACT 2600

Date: November 1989

From: Engineering Heritage Sub-Committee Western Australia Division
(Name of Division or Committee)

This is to nominate the following Work for designation as a National Historic Engineering Landmark:

(Name of Proposed Landmark) Fremantle Inner Harbour

Located at: Swan River Mouth, Fremantle

State: Western Australia Please furnish the address (and map grid reference if a fixed work) Swan River Mouth 32°3.3'S Latitude 115°44'E Longitude

The work is owned by the Fremantle Port Authority.

In support of this nomination the following information is provided:

1. Date of construction (or other significant date):

Breakwaters commenced November 1892; Dredging commenced mid 1894; Wharf Construction commenced August 1896. Harbour celebrated 'opening' with first cargo vessel on May 4th, 1897 and 'full facilities' with first Royal Mail carrier on August 13th, 1900.

2. Name of Key professional personnel associated with the Landmark:

C.Y. O'Connor CMG., M.I.E.E., Engineer in Chief	1891 - 1902
C.S.R. Palmer M.I.C.E., Engineer in Chief	1902 - 1904
Sir John Forrest, Premier of W.A.	1890 - 1901
A.W.D. Bell, M.Inst.CE	1890's
J. Thompson, M.Inst.CE	1890's

E.N. Carlin, W. Leslie, G.H. Royce, C. Good, T.C. Hodgson.

3. National engineering historic significance of the Landmark:

The harbour plan demonstrated superior assessment of oceanographic factors. The breakwaters were the first large scale use of random tipped rock walls in Australia, associated with a harbour dredged to 9 metres.

The works required the introduction of major construction plant, management of a large construction force and integration with the infrastructure of a small struggling colony.

4. Comparable or similar Works (a) in Australia. (b) Overseas.

These works predated major works in many Australian ports. Major Breakwaters followed the construction of the Fremantle breakwaters in Newcastle, Kembla and Adelaide.

The harbour depth provided exceeded that of most other Australian ports of the time.

5. Unique Features of characteristics which set this proposed Landmark apart from other engineering Works, including those of 4 above:

An 8 - 10 year construction undertaking, costing approximately $90 Million (present value), was achieved on time and generally to budget, in a colony which lacked almost all engineering works facilities.

The design managed the environment expertly, resulting in nearly one hundred years without significant modification or maintenance; servicing each generation of ship growth size and variety. It's provision for future expansion minimised future costs and avoided expensive duplication.

6. Contribution which this Work has made towards the development of: (1) the engineering profession and/or (2) the nation:

(a) Engineering Profession

The professional and trade workforce assembled and trained on this project, created a departmental division that confidently and capably designed and constructed many harbour facilities throughout the entire long length of the Western Australian Coast.

(b) The Nation

The works provided a capital city port servicing the Western half of the nation and meeting all aspects of shipping trade requirements. It achieved these goals at a cost which allowed economic handling of shipping and goods thus resulting in a port that has achieved an operating profit throughout most of its one hundred years.

7. In further support of this nomination the following documentation is submitted: (please list all enclosed documents, photographs and supporting historical evidence).

A fully documented submission with photographs and plans has been prepared for forwarding shortly.

8. For completion by Committee or body (other than a Division) making the Submission. A copy of this Submission has been forwarded to the Secretary of the N/A Division at _____.

We have discussed this nomination with the owner of the Work. The owner has indicated that Fremantle Port Authority

will support the nomination, contribute to preparation of a fully documented submission and take an active role in any subsequent marking ceremony on its property.

THE INSTITUTION OF ENGINEERS, AUSTRALIA

NATIONAL HISTORIC ENGINEERING LANDMARK NOMINATION

CONSTRUCTION OF FREMANTLE HARBOUR: 1892 - 1901

Submitted by:

November 1989

Western Australia Division, I.E.(Aust.)

and

Fremantle Port Authority

Research: A.V. URQUHART
BE, Grad.Dip.Admin.
M.I.E.(Aust.), A.F.A.I.M.

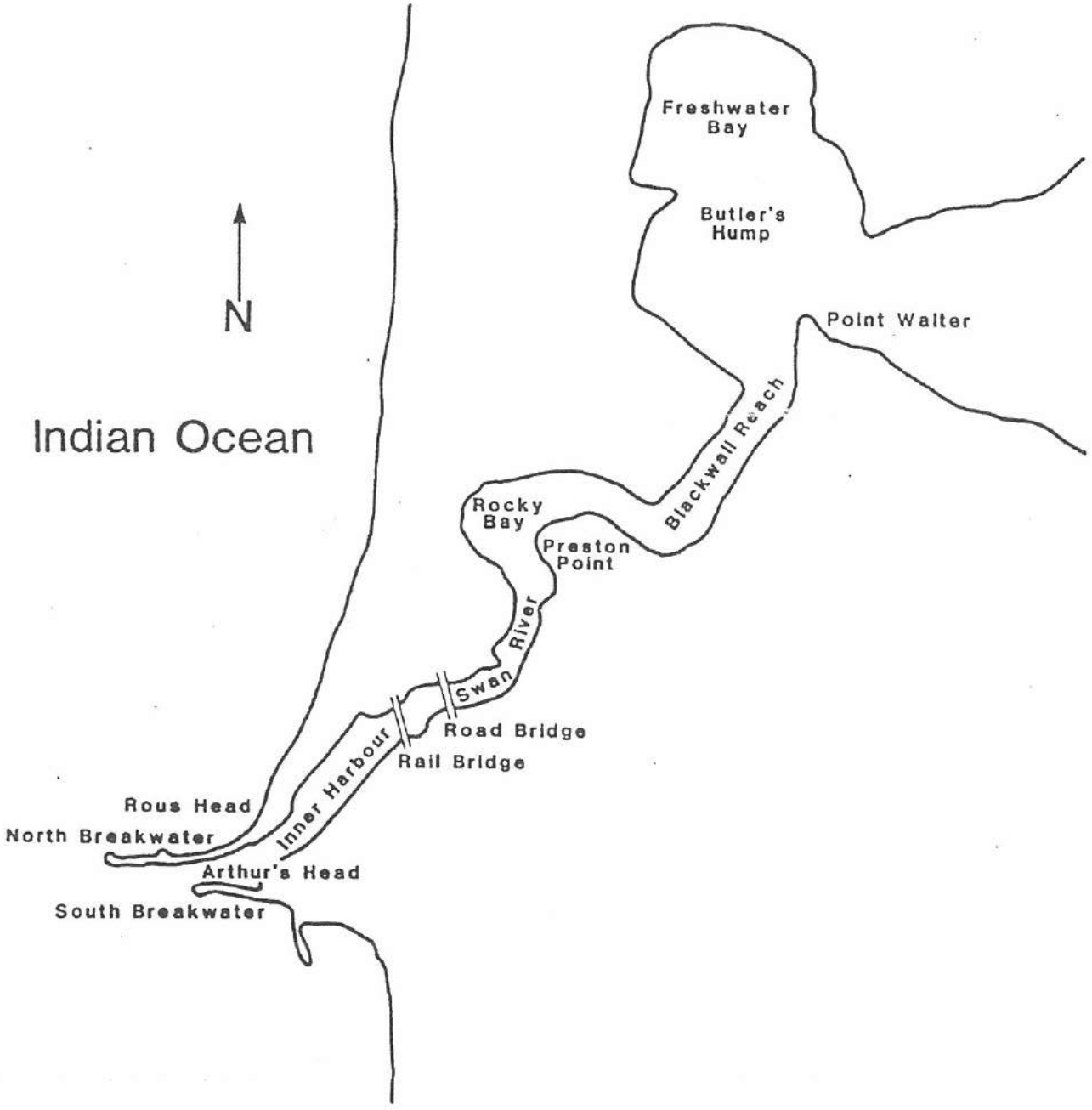
Editing & Compilation: A.V. URQUHART, M.I.E.(Aust.), M.T. MORLEY M.I.E.(Aust.)
and A. MOULDS M.I.E.(Aust.)

Members, Engineering Heritage Sub Committee,
W.A. Division

Prepared for the Engineering Heritage Sub Committee of the Western Australia Division, I.E.(Aust.): with the assistance of the Fremantle Port Authority, whose contribution is gratefully acknowledged.

Acknowledgement is also made to Mr J.S.H. LePage, author of "Building a State" for several illustrations; and to the Institution of Civil Engineers in London for the transcript of Palmer's paper as published in the Institution Proceedings, Paper No.3897

The Port of Fremantle and the Swan River



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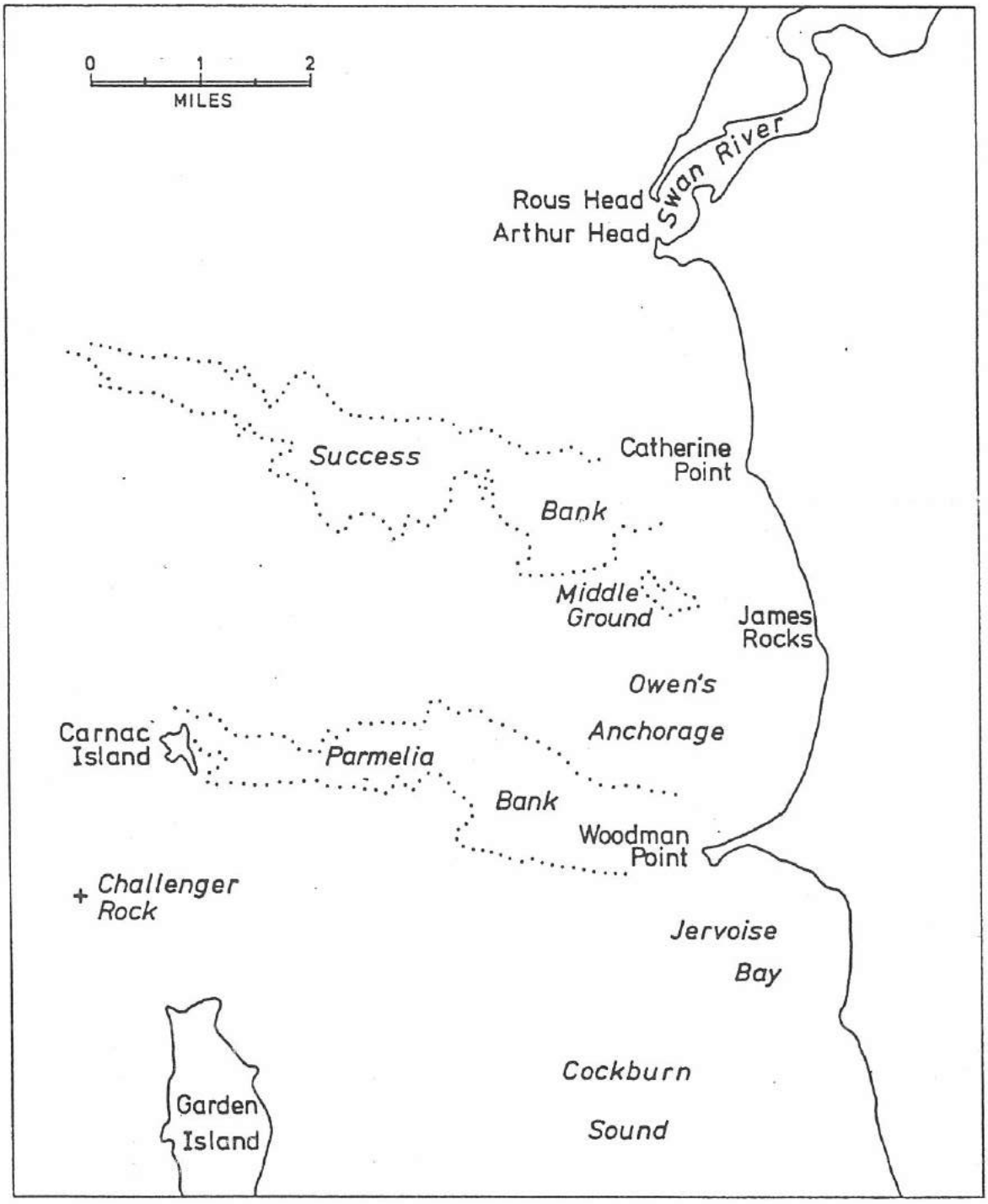

Fremantle Outer Harbour.

NATIONAL HISTORIC ENGINEERING LANDMARK NOMINATION
CONSTRUCTION OF FREMANTLE HARBOUR 1892-1901

FOREWORD

The first party to arrive at the Swan River Colony in July 1829 sheltered at Garden Island to protect their boats from the winter gales.

By September 1830 the Civil Engineer for the Colony, Henry W Reveley, had submitted plans and cost estimates to Governor Stirling for the construction of a breakwater at the mouth of the Swan to protect shipping from the violence of the gales. The cost estimate for the proposal was far beyond the resources of the Colony.

In the subsequent years jetties up to 484 feet in length were constructed adjacent to the mouth of the Swan River to provide berthing facilities for shipping. These jetties provided little protection from the weather, the boats alongside frequently suffering damage. As a result most of the cargo handling was carried out by lighters from ships anchored offshore. Throughout the first sixty years of the Colony the construction of a safe harbour inside the mouth of the Swan River was continually reviewed; however, the cost of breaking through the shallow rock bar across the entrance to the harbour always provided an obstacle to these proposals.

During the years that the construction of a safe harbour at Fremantle was under consideration the application of steam power was providing a revolutionary improvement in transport, this being a vital ingredient for the growth and development of the world economy and in particular integration into it of many new areas such as the Indian Ocean Region.

The application of steam power at sea increased mobility for passengers and merchandise. Between the steamers and the railway there was the need to create harbour and dock facilities to enable them to keep pace with the technological development in steam shipping and economic growth.

With the completion of the Suez Canal in 1869 the steamship played an overwhelming role in the commencement of port construction in the Indian Ocean which would not have been possible without significant advances in civil engineering, including the construction of breakwaters and docks and the introduction of large hopper dredges.

In 1852 a regular mail service was commenced by the Royal Mail Steamship Navigation Company and also the P & O Company using the protected King George Sound at Albany as the port of call. This resulted in considerable resentment from the residents of Perth and Fremantle.

The Colony's population in 1887 was 42,488; however, with the granting of Responsible Government to the Colony in 1890 and the great gold discoveries in the next few years the pressure for a safe harbour increased dramatically to overcome the avoidance of the Port of Fremantle by shipping. By the year 1902 the population of the State had increased to 215,157.

With the appointment of C Y O'Connor as Engineer in Chief and his taking up the position in May 1891 the task of creating a safe harbour was tackled with vigour.

During the first year in office O'Connor had carefully assembled sufficient facts to be convinced that it was possible to construct, at economical cost, breakwaters up to 3,000 feet in length at the entrance to the Swan River, blast out the shallow rock bar at the mouth of the river, and dredge a harbour with a turning basin capable of taking the largest mail steamers in use.

He convinced a Parliamentary Committee convened in January 1892 on the feasibility of the proposals. The scheme was endorsed by parliament in March 1892 and construction commenced in November of that year.

Construction proceeded according to programme and reached the stage to allow the first mail steamer to enter the harbour in August 1900.

By 1903 the scheme had cost $1,458,940 involving completion of 6,840 feet of breakwaters (1,261,274 cubic yards of rock), drilling and blasting of 1,503,099 cubic yards of rock in the harbour, the dredging of 9,637,501 cubic yards of material and the construction of 8,805 feet of wharf and jetty.

The harbour paid its way from completion and has continued to serve Western Australia in an ever increasing way. The harbour was deepened to 36 feet in the 1920's and is presently undergoing further deepening to 42 feet from low water level.

Although the concept of a harbour in the mouth of the Swan River had been studied since early settlement of the Colony, it became the task of C Y O'Connor in his first year as Engineer in Chief to determine the viability of the scheme in terms of cost and the availability of construction equipment to successfully complete the work. This he was able to do contrary to expert opinion at the time particularly that relating to the silting up of the harbour.

It could be claimed that the large breakwater construction carried out at Fremantle led the way for the construction of other large breakwaters such as those constructed at the ports of Kembla (1901), Newcastle (1909) and Adelaide (1909).

The planning of the harbour illustrated O'Connor's perception of the needs for the future in determining the size of the inner harbour particularly in respect to the width of 1,400 feet and its depth. The harbour has continued to serve the needs of Western Australia and should continue to provide for the continually changing role and size of shipping well into the foreseeable future.

J L PATON BE, FIE (AUST)

FURTHER DEVELOPMENT*

Ports are vital links in the international transport system and, for an island nation such as Australia, assume a special importance as gateways to the rest of the world. A recent study of the development of the modern Indian Ocean ports has shown that these ports had a wider significance: they formed the hearts of cities which constituted the meeting places of European and indigenous cultures. In short, the ports facilitated western economic penetration into the less developed parts of the world. For example, the development of the Port of Fremantle, located on the edge of the Indian Ocean, provided the British Empire with a western gateway to the vast Australian continent.

After the opening of the Inner Harbour in 1897, Fremantle quickly replaced its rival Albany, some 400 kilometres to the south, as the main port of call and bunkering port on the Western Australian (W.A.) coast. Between 1903-04 and 1938-39 the volume of port trade grew from 692,000 tons to 1.8 million tons; shipping tonnage increased from 1.4 net registered tons (nrt) to 4 million nrt. Fremantle was called on to make provision for a wide range of cargoes and ship types. Mail steamers and passenger liners in particular placed heavy demands on the port for increased depths and rapid turnround.

Fremantle's wharves were of the marginal type (constructed along the shoreline) rather than the finger piers (built at right angles to the shore) found in most other Australian ports. The latter had only a narrow opening providing access to the shore; they provided a maximum number of berths for a given length of foreshore and were adequate for cargoes and vehicles using ports in the early years of the 20th century. But as trade and motor traffic increased, the narrow approach ways became bottlenecks and traffic was forced to queue in order to get access to the wharves. This problem led eventually to the adoption of marginal wharves. It says much for O'Connor's foresight that, in the 1890s, he chose this type of wharf for Fremantle. Fremantle was the first Australian port to enter Bird's era of simple lineal quayage: Melbourne and Sydney, for example, did not enter this era until 1917 and 1929 respectively.

The success of C. Y. O'Connor's scheme is underlined by the fact that Fremantle's physical lay-out remained basically unchanged throughout the first half of the 20th century. The southern quay of the harbour, Victoria Quay, had a length of 5,055 feet and was used mainly for mail steamers and general cargo traffic. Work on North Quay commenced in 1901 and by 1903 it had reached about 2,000 feet in length. The completion of North Quay in 1916 brought the total length of wharfage in the harbour to 9,875 feet. North Quay was used mainly for the handling of grain exports and bulk cargoes. The total length of wharfage remained about 10,000 feet until 1938 when it was extended slightly to 10,177 feet. Therefore between 1903 and 1939 the length of wharfage grew by about 44 per cent; over the same period cargo traffic grew by over 150 per cent.

A sound physical infrastructure was not Fremantle's only asset: she had only a minimal tidal range removing the need for expensive wet-docks; the port was free of strong currents and serious wind, fog and other weather problems; and only minimal maintenance dredging was required to maintain channel depths. These advantages, combined with her geographical position and favourable railway connections, helped her become W.A.'s 'premier' port.

According to certain benchmarks, by the late 1920s the port was operating close to its maximum sustainable capacity. The depression led to reduced trade levels and consequently pressure on port facilities was also reduced, increasing again only in the late 1930s. Improvements in port organisation and the introduction of mechanical cargo-handling equipment enabled the Inner Harbour to adequately serve the needs of port users until the 1950s when a new era of specialised quayage and Outer Harbour development began.

*Taken from "The Development of the Port of Fremantle, Australia's Western Gateway" M. T. Tull Journal of the Australian Association for Maritime History October 1985.

C O N T E N T S

CONSTRUCTION OF FREMANTLE HARBOUR: 1892-1901

1.0 THE COLONY'S ECONOMY

The history of the effort to establish an adequate port for the capital city of the Colony is entwined with the socio-economic story of Western Australia in the last decades of the Nineteenth Century.

> "I found myself writing an economic history of West Australia, simply to understand the economic history of the Port" -
> Professor Appleyard as reported in 'Daily News', December 21, 1978.

The proposal for the river harbour and the adoption of the scheme resulted, in no small part, from its timing in relation to the development of the State.

Earlier proposals, and their rejection, similarly reflected the Colony's lack of capacity to support major public works during those times.

The two great engineers associated with designs for the port, Sir John Coode and C. Y. O'Connor, were popularly seen as pitted against each other in their opinions - both at the time and subsequently. O'Connor's view was different .....

> "What was supposed to be within the means of the Colony (had handicapped Coode throughout). Had (Coode) not been cribbed, cabined and confined ..... by these financial considerations he would very likely have gone in for opening the river from the beginning."

Over the last three decades of the Nineteenth Century, when more serious professional attention was directed towards solving the port problems, considerable change was being experienced in the population and revenue of the Colony.

PROGRESS OF WESTERN AUSTRALIA

Year	Population of whole Colony	Revenue of whole Colony	Railways in Colony
	Number	Pounds	Miles
1829	Beginning of Colonization		
1875	26,709	157,775	Nil
1877	27,838	165,413	Nil
1887	42,488	377,904	168
1891	53,279	497,670	203
1902	215,157	3,690,585	1,360

> "In December 1885, the Colony's population was 35,000 and in a decade it had grown to 82,000. Most of the increase had been at the expense of the other Australian colonies which, in the early 1890's, were experiencing a severe economic recession and widespread labour troubles." -
>
> Crowley R. K. "A Short History of Western Australia."

The granting of Responsible Government to the Colony in 1890 and the great gold discoveries of the next few years, changed the scene .....

> "the resulting rapid increase of population, trade and resources, enabled and compelled the newly enfranchised people to start extensive improvements of their estate, not the least of these being harbour facilities."

Nevertheless, the financing of major capital works was still difficult in Australia .....

> "The reluctance of the first parliament to authorise a large capital outlay is understandable when it is recalled that developmental works could be paid for only with overseas loan funds and interest and sinking fund charges would impose a serious toll upon the limited revenue of the Colony. While parliament was in recess, 25,000 Pounds of the 4% loan of 1,336,000 Pounds authorised in 1891 had been raised in London at a premium of 10 s 10 d. At that time Western Australia was the only Australian Colony able to raise funds in London. Loans opened in London by Victoria, Queensland and South Australia failed.
>
> The remaining finance was obtained from London buyers of the Government's bonds, and the Colony's public debt trebled in the four years after 1890, because of railway construction and other important public works."
>
> Crowley R.K. ibid.

In the context of these harsh economic times, Fremantle had another impediment to its costly port solution. It lay in the natural harbour that existed at Albany some 250 miles to the South. Indeed, Albany was settled first, mail steamers only called at Albany and Royal Mail Steamers continued to ignore Fremantle until the turn of the century.

What was the difficulty in establishing a port to serve the Colony's capital city?

2.0 (EARLY) HISTORY OF THE PORT

The Port of Fremantle officially dates from the appointment of its first Harbour Master under a British Act of 14th May, 1829 - the year of first settlement of the Swan River Colony.

The Colony's first appointed civil engineer, H. W. Reveley, was soon requested to prepare a submission for port works.

"Fremantle Harbour"

Later in 1830 Reveley became the first of a long list of engineers and others to advance proposals for the development of a harbour at Fremantle:

> Civil Engineer's Office
> September 17th 1830
>
> Sir
>
> In obedience to the Command of His Excellency the Lieutenant Governor I transmit herewith a Plan for a Breakwater proposed to be constructed at the mouth of the Swan River in order to protect the Boats and Shipping from the violence of the Winter gales.
>
> The Estimate of the expense of this work at the prices at which the Plymouth Breakwater was executed amounts to one hundred and sixty five thousand Pounds for the thousand yards in length laid down in the plan and twenty one thousand Pounds for the first five hundred yards which will completely protect the entrance to the River.
>
> I am
> Sir
> Your Obedient Servant
> Henry W. Reveley.

Even the twenty one thousand Pounds for the five hundred yard breakwater was completely beyond the reach of the infant Colony's meagre resources. To fully appreciate its significance it should be compared with Reveley's summary of all public works from June 1829 to March 1831 which totalled less than four thousand Pounds. The matter of a harbour for Fremantle would have to wait for a long time yet.

During its first sixty years of settlement the lack of a harbour at Fremantle severely hampered the growth of the Swan River Colony.

As breakwaters, whether associated with a river harbour concept or not, were clearly beyond the Colony's resources, shipping trade relied on unprotected jetties projecting out

from the semi-exposed coastline alongside the Fremantle settlement.

2.1 The Jetties

The first jetty was built in 1832. This extended out from Arthur Head on the south bank of the Swan River. The South Jetty, built out from the adjacent South Bay was commissioned in 1854. However, the first substantial structure for berthing vessels, the Ocean Jetty, was not commenced until 1872.

By 1875, three small jetties had been constructed, one in the river in five feet of water and two just south of Arthur Head in eight and twelve feet of water, respectively. The bar at the mouth of the river prevented it being used for navigation, while any jetty advanced beyond the shelter of Arthur Head became subject to the full force of the north-easterly weather.

> 'The Fremantle Herald' of October 24, 1868 noted that -
>
> "at this moment the navigation of the river is all but closed in consequence of the attempt to make a channel on the north side of the bar which would, if it succeeded, shut out Fremantle altogether and make communication between Perth and the roadstead direct. As it is, the attempt is a complete failure.
>
> At its deepest point and in fine weather vessels drawing only 12 feet of water could berth. In bad weather they had to haul off. Vessels drawing more than 12 feet had to lie off in Gage Roads and be loaded and unloaded by means of lighters, when available, passing to and fro between ship and shore."

While the Ocean Jetty was extended finally in 1896 to a total length of 3800 feet and thus provided a greater number of berths and 20 feet depth of water, its exposure to weather increased. This exposure applied to both summer and winter prevailing winds.

As trade increased, particularly in the boom years of the nineties, the cumulative effect of a single jetty neck servicing an exposed berthing head, with other vessels being serviced at anchor in Gage Roads by lighter, caused delays of up to 75 days with sometimes up to 30,000 tons of cargo being involved.

Such was the persistence of this situation that 'the block' became a well known term throughout shipping circles.

When delays occurred costs to shippers were increased. Freight charges to Fremantle were higher than to any Australian port; handling charges were heavier than anywhere else on the Australian coast. Altogether Fremantle was a port to avoid.

Newspaper articles on 'the block' abounded at the time - a selection is included at Appendix A.

Not only were cargo handling costs threatening the demise of Fremantle as a trading post. The exposed conditions were a continual concern to the Port Authorities and ship masters alike. The colourful reports of the times leave little doubt as to the tenuous future of this capital city port unless alternative harbour facilities were forthcoming.

Even as late as 1892 an incensed American sea-captain, writing to his principals in New York, confirmed the harbour master's criticisms. Captain D. B. Shaw, commanding the sailing ship "SARANAC", arrived from New York on 21 October 1892 to unload half his cargo at Fremantle before proceeding to Launceston with the remainder. His report of Fremantle was blistering. It was 24 October before he entered and fought against putting the vessel alongside jetty to discharge.

> "It is a terrible place. No place to put a vessel. No shelter whatever. All the ships have to lay and discharge at the wharf or pay lighterage. It is blowing a gale from the SW... and takes all our time to hold her. She had done considerable damage to herself. It is certainly the worst place I or anyone else ever saw. No place to send a ship of this size. Any man who would come or send a ship a second time is a damned ass."

In one of his letters dated 8th November 1892, he says:-

> "The weather has been very bad ever since I arrived and tonight it is blowing a gale of wind from the south-west. My lines are all used up and I have got two springs hired to make her fast aft, and out ahead I have my anchors down with 75 fathoms of chain out and all the remaining lines that I have left, and one of my bow chains fast to the wharf, and it takes all our time to hold her. She has done considerable damage to herself. My after bits are broken off level with the deck. My stern chocks are pulled out and

about 10 ft of the rail all torn off, including two stanchions. All of my channels next to the dock are more or less damaged. About 8 ft of my main rail is split off and one hawse pipe gone.

The bufalow on the starboard side of the top gallant forecastle all twisted up. My lines are all ruined. If I get clear without any more damage I will be in luck."

2.2 The Alternatives

While all parties agreed on the disabilities of the port, there was little consensus on the location, type or costs of alternative facilities. Rather, each scheme promoted was treated with derision, as newspaper reports of the times reveal.

"Opposition to this scheme favoured the removal of the bar and deepening the channel so as to permit the entry of ships of 500 tons burden going to Perth". The Herald in its forthright manner, decried this as being "about as practicable a project as a railway to the moon."

Bickley, the designer, subsequently wrote:-

"It matters little whose plan is adopted, whether mine or any other persons, so long as the plan is effective and economical - only, for goodness sake, let us have no more futile tinkerings at the bar, or any waste of money upon any similar childish mischievousnesses."

The bar, varying considerably in the hardness of its coralline limestone and sandstone also varied in its elevation, up to Low Water Mark. Coupled with a negligible tidal range, it defied the ingenuity, skills and resources available to the Colony.

In the early seventies, because of the considerable difference of opinion as to where the harbour ought to be situated and what form it would ultimately take, three Victorian engineers, whom the colonists consulted in the matter, strongly recommended a site at Cockburn Sound as the solution of their difficulties. Mr. Wardell C.E., of Sydney, reported that any solid work projecting from either Rous or Arthur Heads, would cause the coastal sand-drift to silt up the river mouth. This matter of sand-drift proved to be a real and lasting obstacle to any plans for an inner harbour. Yet, there is little evidence that anybody took the bother to question whether it was a reality or not.

Again, the Colony found itself with solutions offered that it either did not like or could not afford. A port in Cockburn Sound (really Owen Anchorage) did not appeal to the business interests of Fremantle or Perth and was certainly well removed from the centre of gravity of the Colony's urban population. Clearly, added costs would arise from increased water-borne and land-borne transportation.

2.3 Sir John Coode

The Colony decided to cast its net further afield to secure the services of an expert. Its desperation and enforced determination to find a solution for a port design and location, resulted in engaging the world-wide respected, and expensive, consulting marine engineer, Sir John Coode - as renowned for his business acumen as for his engineering expertise.

Coode made two reports to the Colony, one in November 1877 based on papers submitted to him and the other in March 1887 after a few weeks stay in the Colony.

Coode's second report was, in part, based on the results of borings he had requested be taken of Success and Parmelia banks, which protected the Owen Anchorage and Cockburn Sound basins. From these logs, showing the banks consisting totally of marine sands, Coode concluded they were fed by the southerly movement of sand along the coast.

Thus his second report again emphasised his acceptance of the idea that serious littoral sand travel existed at and near the coastline.

This influenced the form of the harbour he recommended and led him to reject suggestions to use the river mouth or the Rocky Bay site (an alternative cut into a basin further up-river).

Coode reported that to provide for the unimpeded movement of sand, it would be necessary that any sheltering work at Fremantle should be detached from the mainland. The work, he went on to say, would be connected with the shore by an open viaduct, so arranged as to admit the unrestricted passage of sand without causing its deposition.

His second report offered the alternatives of two start points - Arthur Head and Rous Head, on opposite sides of the river mouth.

In relation to the first site, Coode was later to write,

> "I arrived at the conclusion that the form of the work at that time best suited to fulfil the conditions of the case would consist of an open timber viaduct, 1800 feet in length, extending from Arthur Head in the direction of Beagle Rocks, terminating with an L shaped solid pier, the two arms of which would be of the aggregate length of 1500 feet. In addition to the foregoing, I proposed a spur jetty of 300 feet in length, to be formed at the junction of the viaduct with the solid pier, so that the total amount of berthage under this project would have been 1800 feet in length in a depth of 20 to 27 feet at low water."

The second site, at Rous Head, provided for an open viaduct, 2600 feet long, running in a north-westerly direction from the low headland into 29 feet of water.

At the end of this viaduct was a breakwater of concrete blocks in four connected sections towards the south-west, providing protection to berths on the lee side of it and also to an open-piled jetty of 800 feet and a wharf of over 700 feet. The works of such an outer harbour would, of necessity, be broadside on to the worst weather. In this connection, Coode stated that having watched a north west gale, observed the "wave stroke" that would fall on artificial works in a gale, he was satisfied that nothing less than structures of solid concrete would meet the conditions of the case in a permanent and satisfactory manner.

In all, the plan provided a total wharfage of 4100 feet at depths varying from 29 to 33 feet at low water.

Its estimated cost was 638,000 Pounds - nearly twice the annual revenue of the Colony at the time of submission.

2.4 Further Options

The period between Coode's reports of 1887 and 1891 did not advance the cause for an acceptable harbour in any visible way, but more mature and determined thinking was growing within the administration of the Colony. Each option was examined - not necessarily with expertise and often from a vested interest approach.

The sixteen plans, reports or proposals known by 1891 fell into four groups. Three groups were concerned with constructing an outer harbour with works extending from Rous Head or from Arthur Head, or at some site within Cockburn Sound. The fourth, providing for an inner harbour at the river mouth or in the Rocky Bay area, had received scant attention. In the face of technical difficulties and limited resources, the emphasis had been placed upon an outer harbour. Certainly in 1890 and 1891 Forrest was thinking of an outer harbour, in Owen Anchorage. By that time he had reopened discussion with Sir John Coode.

Premier Forrest also reopened the question of a harbour for Fremantle in parliament.

In debates on his first loan bill he made clear his intention:

> "It must have been known to members that the government was going to stand on Sir John Coode's scheme. With characteristic impatience he now requested an opinion from Coode of what effect certain contemplated improvements at Fremantle would have upon his minor scheme of 1887. But even before Coode could answer the several questions pressed upon him, Owen Anchorage had found favour with the Premier as a possible site for a harbour for mail steamers."

Clearly the problems associated with establishing a port to service all present and realistic future requirements of the area, overpowered the will of the various leaders of the Colony, even including the self-confident Sir John Forrest.

What was needed was an experienced professional marine engineer with the skill, confidence and strong will to conceive and force through all stages, the construction of a harbour adequate for a capital city.

By the luck of a second choice, the Premier and the Colony got exactly such a man, in C.Y. O'Connor, M.INST.C.E., as the appointed Engineer-in-Chief, in 1891.

3.0 O'CONNOR'S CONCEPT

3.1 The Problem

Immediately he arrived O'Connor faced Forrest's programme for development, a programme with public works in plenty. But he found that no Department of Works existed, there was no staff, workplace, or accommodation.

On the pressing issue of harbour establishment, O'Connor reviewed all the collected data and reports available to him - both technical and political.

- It must also be assumed that he was soon acquainted with public opinion and the forces pressing for alternative solutions and sitings for the harbour.

The conflicting list of information included the following:-

- littoral sand drift was a significant feature of the coastline (Coode).
- this would silt up any river-mouth based harbour and possibly any channel cut through the banks leading to Owen Anchorage and Cockburn Sound.
- the river-borne material would also silt any dredged opening and require expensive maintenance dredging.
- sea defence structures would need to be made of concrete to withstand the energy of storm waves in this location (Coode).
- the bar could not be successfully removed.
- ship handling (particularly those under sail) would be difficult in any harbour exposed to westerly winds.
- the Fremantle population opposed a site remote from the town but
- the Premier favoured an Owen Anchorage site, at least for a Mail Boat jetty.
- others favoured an up-river site at Rocky Bay.
- the Premier, the Colony and particularly the business community considered expenditure on a harbour could not be countenanced above one hundred thousand Pounds.

3.2 The Problem Investigated

During 1891, the first year of his appointment, O'Connor narrowed the schemes down to these possibilities -

(1) A cut at Rocky Bay, by-passing the river bar.

(2) A channel across Success Bank opening up Owen Anchorage to Gage Roads.

(3) Opening up the mouth of the Swan River.

O'Connor made it his immediate task to examine Sir John Coode's plans and to scrutinise his correspondence with the Premier.

Throughout the latter half of 1891 while Forrest continued to pursue the idea of an outer harbour and to press further questions upon Coode's attention, O'Connor was assembling data that would enable him to form a judgement.

In early September 1891, at the urging of the Premier, O'Connor estimated what works could be obtained for an outlay of 150,000 Pounds on site at Owen Anchorage approximately 2 miles south of Fremantle. An additional 50,000 Pounds, he pointed out, would be required to purchase dredges, to build a railway with the necessary facilities and to connect the harbour at Owen Anchorage with the existing town of Fremantle and the railway leading to the Capital and beyond.

On the basis of the data he had assembled, O'Connor was convinced that the information made available to the English engineer was inadequate and that the claim of serious littoral sand travel, if in fact it existed, had been over-stressed. He concluded that Sir John Coode had thus been led to abandon any thought of the river mouth as a possible site for a harbour and to advocate an outer harbour constructed in a particular way.

Twenty years later his old friend, Darley, opening a discussion on Fremantle harbour works, spoke of the manner in which O'Connor came to reject the theory of sand travel which Coode had accepted:

> "Fremantle Harbour was another case of a theory set up in the old days with regard to sand-travel.... Sir John Coode accepted the theory that there was a movement of sand along the coast (at Fremantle) but, of course, he was not there long enough to make a study of the subject himself and had to accept the views of those in authority at the time.... Mr. O'Connor made a

> close study of the matter and knowing that so many engineers before him had accepted the theory of sand-travel, he was very slow and cautious in acting against that theory. Having collected all the evidence he could get, Mr. O'Connor rightly came to the conclusion that there was nothing to be feared from sand-travel."

On the question of river-borne silting material, O'Connor dismissed the concern immediately. He considered that, with such a small tidal regime, the quantity of silt could not be significant.

> "He ridiculed the suggestion that sand drift would silt up the harbour mouth. This fear which had become more popular following Mr. Wardell's report in the seventies and which had so strongly influenced Sir John Coode's subsequent recommendations, was not borne out by the facts. Testing in the spot had proved this and the opinions of local fishermen and others with a long knowledge of the sea floor in the vicinity, confirmed it."

Further, O'Connor considered, if siltation did eventuate it could be reasonably cheaply counteracted by dredging.

In support of his case, he cited the recommendations of Sir John Coode in a harbour with comparable difficulties, where Sir John had estimated that the expenditure of 4,000 to 6,000 Pounds per annum would overcome this evil - the harbour at Timaru, New Zealand.

No doubt this evaluation reflected the changing cost significance of soft sediment deposits in the marine world, due to the increased efficiency of suction dredges becoming available on the world market.

3.3 The Owen Anchorage Distraction

Premier Forrest, as already noted, deeply concerned with establishing a Mail Boat facility, continued during 1891 to state his determination for an Owen Anchorage site.

> "Our object is to make Fremantle a port of call for Mail Steamers as quickly as possible and the only chance we have of doing it is to try to do something at Owen Anchorage. I cannot see any other alternative within our present means."

O'Connor was instructed therefore to prepare a draft plan and estimate for the Premier.

The estimates prepared for Forrest by O'Connor showed what an outlay of 150,000 Pounds could provide at Owen Anchorage: a channel cut through Success Bank, with a bottom width of 400 feet and a depth of 30 feet, a jetty 2,000 feet in length, only the outer 500 feet offering a depth of water of 20-25 feet, a protecting mole of 3,000 feet and 3 miles of railway to connect with the Fremantle rail terminus. To ensure a first-class harbour at Owen Anchorage a sum of 400,000 Pounds or probably 500,000 Pounds would be needed.

Although the new Engineer-in-Chief was grossly over-loaded with the other works and duties required for the Colony, this 'distraction' of the Owen Anchorage Solution served to crystallise the issue of harbour site and costs.

It provided a clear cost effectiveness yardstick for O'Connor's embryo scheme of a river port.

This situation was quickly seized upon by the third influential figure in the drama - the Director of Public Works, Mr. H. W. Venn, who, as a member of parliament and the Government, was the equivalent of todays' Minister of Works.

Upon receipt of O'Connor's Owen Anchorage submission, Venn told Forrest that for such a sum "an almost perfect land-locked harbour could be made at the mouth and in the river itself for all vessels drawing certainly not less than 30 feet."

3.4 The Solution

Clearly O'Connor had already convinced his political boss that he could successfully achieve what other engineers had considered a risky plan. Within three days of the Owen Anchorage submission Venn wrote to O'Connor:

> "It now comes to this: I would ask you to send me an approximate cost of forming a suitable harbour at the mouth of the River - this is following up the conversations I have had with you at different times."

O'Connor submitted two sets of plans.

The first provided for works "sufficient for years to come" - a north and south mole to protect the entrance to the harbour, a dredged outer channel and an inner basin with 3,350 feet of wharf on the south side. The reclamation of 19 acres on both sides of the river was necessary and the estimated cost was 560,000 Pounds. As against this scheme, which would take 5 years to complete, O'Connor prepared a second design to meet

the requirements "of the largest class of ships that might be expected to be necessary to provide for in the next generation or so". This gave 2,900 more feet of wharfage and a larger inner basin, a greater amount of land to be reclaimed, but in other essentials it was merely an extension of the smaller scheme. It would take 8 years to complete and would cost 800,000 Pounds.

The plan was practical, took account of the resources of the Colony, it was economic and would give a harbour of the standard Forrest was anxious to secure.

It was a basic tenet of O'Connor's planning that any harbour design must allow for the rapid changes taking place, at the time, in ship-building and cargo handling. "The harbour built today, must be capable of being expanded and improved to accommodate the vessels and trade of tomorrow."

O'Connor's inner harbour scheme revealed his striking independence of mind. The plan showed a harmonious simplicity. Happily, he combined a capacity for brilliant planning with an appreciation of the practical issues involved. When the feasibility of his proposals could best be critically appraised by men experienced in handling ships he invited their comment. Sea captains, harbour masters, pilots, those who handled ships - he consulted them all. Willing as he was to consider other men's ideas or to take account of other men's experience, he was never over-awed by the opinions of others.

3.5 The Solution Debated

However, the scheme again raised the issues previously propounded by opponents of the river option.

With Forrest still convinced that he would get his Mail Boat facility quickest at Owen Anchorage, an impasse was clearly ahead or, indeed, it could result in Forrest making an unilateral decision to commence the Owen Anchorage scheme.

Fortunately, the Colony had now arrived at a greater level of administrative maturity.

On 19 January 1892, Charles Harper successfully moved the appointment of a Joint Select Committee of both Houses to inquire into the question of Harbour Works at Fremantle, and having regard to the amount at present available, report what plan would be the best to give secure accommodation to the largest class of ocean-going steamers. Forrest now had no option but to await the report of the Committee. This Committee

consisted of the Minister for Works, Venn (Wellington) the Minister for Lands, Marmion (Fremantle) and three other members of the Assembly: Charles Harper (Beverley), A. R. Richardson (De Grey) and W. S. Pearse (North Fremantle), together with five members of the Council: W. D. Moore, E. T. Hooley, T. Burges, G. W. Leake and M. Grant.

The Committee was composed entirely of laymen. The witnesses called, in addition to O'Connor, included J. Arthur Wright MLC, from 1885 to 1889 holder of the triple appointment, Director of Public Works, Engineer-in-Chief and Commissioner of Railways to the Colony; Francis William Martin, O'Connor's former colleague and a marine engineer with many years service on the west coast of New Zealand, now a member of the staff of the Department of Works and Captain C. R. Russell, the Chief Harbour Master.

In giving evidence before the Select Committee, O'Connor displayed both dignity and patience. Some questions were asked to obviously anger him. "Do you think that after the country has decided to refer matters to an eminent marine engineer his opinions should be totally ignored in favour of the opinions of others - civil engineers and amateur engineers?" To this, and other questions referring to his opinions and those of Sir John Coode, he replied that there was no conflict between his ideas and those of Sir John Coode, adding that it was difficult "for layman to form an opinion as to whether one engineer's views were in conflict with another engineer's views upon purely technical points."

With opposition continuing to be evident during the hearing, O'Connor demonstrated his professional attitude:

> "I have deliberately given my opinion that these works are practicable. I have done so unhesitatingly, and without providing for any other authority to be consulted . . (however) I have not the slightest objection to the Government referring my scheme to any other authority . . . all I stipulate for is that they should be submitted in their entirety and not piecemeal . . . as a whole and not part of a scheme."

Finally the wisdom of Venn's statement, made as a member of the Select Committee, appears to have convinced all members.

Venn's Statement

> "I cannot help thinking that the country will never be satisfied and will never rest until (the providing of an inner harbour) is done, because when once done its advantages over every other scheme are so apparent and so real as to commend itself to one's judgement as being the wisest and best thing to do . . . viewing it in this light every 100,000 Pounds spent at Owen Anchorage is an additional charge against the Inner Harbour Scheme - and must be counted as such by us, as we would be committing the Colony to this expenditure knowing and feeling that at some very short period the Inner Harbour Scheme would supersede it entirely, and then would come the question of vested interests at Owen Anchorage . . . in its town and in its surroundings."

After sitting for seven days, the following two resolutions were moved:-

1. "That the evidence given and the opinions expressed to this Committee by the engineers and nautical authorities consulted point strongly to the superior advantages of opening the mouth of the Swan River over any other project, and this Committee therefore is of the opinion that the scheme as recommended by the Engineer-in-Chief and shown on PWD WA 1468 should be adopted."

2. "That this Committee is of the opinion that inasmuch as there is a sum of about 134,000 Pounds available for harbour works at Fremantle, and that the Engineer-in-Chief advises that by the expenditure of about 250,000 Pounds the scheme he recommends for the opening up of the river can so far be completed as to be available for the largest class of ocean steamers, it is desirable that this work should be undertaken without further delay."

Taking the Committee's final point literally, the scheme was successfully introduced in the Legislative Assembly on March 9th 1892.

John Forrest, convinced that expert and lay opinion agreed upon the advantages of a harbour in the river mouth, abandoned his own preference for a site at Owen Anchorage, telling the House he was pleased with the turn of events. He congratulated the country on having such an authority as O'Connor as their Engineer-in-Chief, stressing that O'Connor was very much aware of the responsibilities he had taken upon himself. If doubts existed in Sir John's mind he was careful not to express them and in the event of the

project proving a costly failure it was apparent who was to be blamed.

The Upper House, with most speakers in euphoric mood, endorsed the proposal five days later.

During the debate J. Arthur Wright noted that:

> "I have great pleasure in seconding this resolution, the more so as the scheme is one which I have always had the greatest faith in. A scheme about which I have had my share of abuse inasmuch as it was said that I had set myself up in opposition to one of the greatest marine engineers, Sir John Coode. I advised in accordance with my duty to the best of my ability and I am glad to find that my view has been at last adopted. I advised that we should take advantage of the river which we possess at Fremantle. Sir John Coode thought otherwise, as he said that small vessels might only be brought up. There have been such great improvements in the machinery for operations of this kind, that now what was a difficult matter is comparatively easy. I feel perfectly certain this work can be carried out and that it will prove of the greatest advantage to Fremantle and to the Colony. It will prove in fact the only work that will be of advantage to the commercial interests of Fremantle. There will be a very large amount of land reclaimed and the proceeds of the sale of it will go a very long way towards the cost of this work."

J. W. Hackett drew attention to plan PWD WA 1468 which showed both north and south breakwaters as well as substantial dredging and reclamation. He wished to be advised whether in voting on the issue the Council was approving the full 800,000 Pounds scheme or only the works to the 150,000 Pounds on the Loan Schedule. In reply, the Colonial Secretary George Shenton reassured him that although the Council was voting on the full scheme in principle the Legislature would have to be consulted for each subsequent request for additional funds: Hackett expressed complete satisfaction.

And so at last something other than the writing of designs and plans was to be done and work was to start on the biggest Public Works project thus attempted in Western Australia, the building of Fremantle Harbour.

Nine months later, a leader writer, showing scant understanding either of the thoroughness of O'Connor's preparations or the handicaps under which he worked, revealed how a layman viewed O'Connor's work:

> "The Premier had advocated a different scheme. The Engineer-in-Chief was himself untried and unknown to West Australians. Above all he nearly wrecked all his chances by waiting until the very eve of the final decision before giving expression to his views. But through all this time, he was collecting material, examining the various projects, studying the conditions of the ground, bringing his great experience to bear, devising, testing, deciding. Patiently and unhasting he worked out his theories . . He was enabled to put his case before the Joint Committee of both Houses so perfectly and unanswerably that conviction followed on his evidence. The government accepted the report of the Committee."

Public opinion gathered force as many realised the advantages of having the harbour inside the river. Oddly, as far back as 1848 Fremantle residents had opposed the removal of the bar for fear that ships would make Perth their port and by-pass Fremantle, but the Fremantle Traffic Bridge, opened in 1867, now made the river unnavigable for trade to Perth.

However, both public and private doubts often led to attacks on the scheme, and its conceiver, throughout the period of detailed design and construction.

4.0 PLANNING, DESIGN AND CONSTRUCTION

4.1 Staffing

O'Connor found on his arrival that professional men would have to be recruited from outside the Colony, equipment obtained and working accommodation created for key men. In the Colony every essential appointment was questioned if not actively opposed. Local feeling was strong. The call for professional expertise caused antagonism.

In 1891 Western Australia was little known and offered little attraction to professional men. For example, G. T. Poole held the various offices of Acting Director of Works, Colonial Architect and Superintendent of Works concurrently. The commencement of work upon O'Connor's plan for the inner harbour at Fremantle, Forrest's programme of economic development and the astonishing gold discoveries in 1892 and 1893 changed that. Until that time, in order to act quickly O'Connor sought out engineers whose quality and professional expertise he knew. James Thompson, an engineering graduate of Dublin with experience in Britain and Victoria came to join O'Connor. By 1893 three experienced engineers from New Zealand, where continued economic stress, curtailment of capital funds for public works and staff retrenchments offered an uncertain future, had come to join him: F. W. Martin, with a full range of experience of harbours and railways on the west coast, W. W. Dartnall, versed in railway construction, and A. W. Dillon Bell, New Zealand born, with English training and wide experience both in Britain and New Zealand, who was often to serve as Acting Engineer-in-Chief when O'Connor had to be away.

Later, following O'Connor's death in March 1902, C. S. R. Palmer was promoted to the position and continued the works as part of his duties.

As the duties of the Engineer-in-Chief encompassed all the public works of the Colony, this group of engineers, and others, were not confined to harbour works alone.

As it became possible to provide special branches within the Department of Public Works, Temple Poole, who was appointed Assistant Engineer-in-Chief following C. Y. O'Connor's appointment, became responsible for the Architectural Division until his retirement from government service on June 30 1897 after 6 months' leave from January 1897. During those years of economic growth in Western Australia he contributed to public building of fine quality and beautiful design, a lasting legacy. He was succeeded

by Dillon Bell, who became responsible for the Architectural Division of the Department until his transfer to the Harbours and Rivers Branch as Engineer-in-Charge in January 1903. In the early years these engineers, together with Thompson, 'the courteous, debonair Irishman', formed with O'Connor a small staff, closely knit by mutual trust and loyalty. 'Between us' said Thompson, 'we had to do everything.'

The Colony's lack of suitable tradesmen, dredge and plant operators, men with mining experience and men used to major construction works was also extreme. However, the build-up of a competent day-labour workforce of up to 450 men was achieved - largely facilitated by the influx of all classes of workers in the gold-rush.

4.2 Design

A key feature of O'Connor's original concept was its dimensional adaptability -

- able to be changed as experience of climatic conditions dictated eg. the northern breakwater
- able to be constructed with more generous dimensions as finance and opinions dictated eg. widening of the harbour swinging basin
- able to be extended in berth lengths or deepened for greater draughts as shipping numbers and sizes increased.

While the location of the root of both breakwaters 'fixed themselves' at Rous and Arthur Heads, their planned shape, orientation and length were modified and 'fine tuned' - no doubt as O'Connor and other newly-arrived engineers confirmed their observation of the wave regime.

There are no known records of the private working papers of these engineers. The issues and changes that are known are mainly those published in the contemporary press and then principally because of their political flavour.

4.3 The Planned Works

The new harbour plan consisted of the following principal features:

a) The throwing out of the two ocean moles from the north and south heads of the river estuary to protect the entrance.

b) The blasting and dredging of a Channel 450 feet wide and a depth of 30 feet below low-water mark through the rocky bar.

c) The dredging to a depth of 30 feet below low-water mark of an inner basin 4,000 feet long and 1,400 feet (originally 800 feet) wide between timber quays constructed along both sides.

d) The reclamation of some 54 acres of Quay and Warehouse space on the South side of the river and of about 22 acres on the North side.

e) Levelling down of Arthur Head to form additional space for railway sidings and goods sheds etc.

No records exist of any formal programme or schedule of works. However, a timetable of actual works achieved has been compiled at Appendix E.

For the breakwaters, O'Connor's experience elsewhere and his assessment of local shore conditions, convinced him that random tipped stone, the Pierre Perdues method. would provide adequate strength.

This choice had the advantage of economy, which enabled his original estimate to be kept within bounds likely to be accepted by the Colony. It also utilised the adjacent resources of the Colony, where limestone predominated. And, again, it also allowed for a readily changeable height, width and rock size specification.

4.4 Construction Planning

In view of the range of alternative plans in evidence on O'Connor's arrival in the Colony, the extent of opposition to the "newcomer's" scheme and the limitations of guaranteed funding, the works were commenced in an impressively short time.

O'Connor had arrived in Perth on Monday June 1st 1891, a Foundation Day public holiday and began active work on Tuesday the 2nd. Parliament approved the scheme in principle at the end of March 1892 and stone-tipping on North Mole commenced on November 16th 1892.

4.5 The Breakwaters

The preliminary works were soon commenced. The construction of the North Mole, as the breakwater was usually called, was the first priority and the stone was to come from limestone quarries at Rocky Bay. This required a railway connection, rolling stock, and steam cranes.

With the exception of the parapet on the North Mole, both breakwaters were built entirely of tipped stone, the stones being allowed to take their own slope; end-tip trucks were used to form the leading roads, and side-tip trucks for widening out.

On November 16th 1892 Lady Robinson, wife of the Governor, Sir William Robinson, officially started the construction of the North Mole by tipping the first load of Rocky Bay stone at Rous Head. The largest engineering project yet attempted in the Colony was under way.

A typical parliamentary inspection trip to the site of the works is described by a newspaper journalist of the time, at Appendix B.

It is likely that many professional and port authorities throughout Australia took a keen interest, particularly in the performance of the Pierre Perdues type of breakwater construction.

At Newcastle, a causeway had been constructed to Nobbys in 1846 and extended in 1875-83 by 1,500 feet. However, the major works on breakwaters in Australia appear to have closely followed on from that at Fremantle.

- Newcastle's North and South breakwaters were constructed to 3,300 feet and 4,500 feet by 1909.

- Kembla breakwaters commenced in 1901.

- Adelaide's Outer Harbour breakwater was completed in 1909.

Work continued on the North Mole but the quality of stone from Rocky Bay gradually deteriorated. It was found to be lighter than O'Connor's estimate of 2.64 specific gravity, and was also more friable than the earlier stone. Eventually it was necessary to substitute granite from a new quarry at Boya at somewhat greater expense. This stone had a satisfactory specific gravity of 2.73. Boya, in the foothills of the Darling Escarpment was 24 miles beyond Rocky Bay.

On July 1st 1893 the tip-head had advanced 1,180 feet into 13 feet of water and by July 1st 1894 it had reached 2,300 feet in 28 feet of water and was advancing at nearly 100 feet per month. In one year nearly 30,000 truck loads totalling 214,000 tons were tipped at an average cost of 2s. 4½d. per ton.

By mid-1894 the North Mole was providing sufficient protection to permit the South Mole and the dredging to commence. The South Mole was constructed entirely of the arenaceous limestone or calcareous sandstone. This was obtained initially from levelling down part of Arthur Head and later by switching the Rocky Bay stone to the South Mole.

The preliminary works for the South Mole were commenced in May 1894 and the cliff at Arthur Head was cut down to a bench to enable the root of the mole to be started.

A new railway bridge 693 feet long, primarily for the passage of stone trains from Rocky Bay to the South Mole, was constructed alongside the existing railway bridge in 1895. After being used for the stone transport it was available, with the existing bridge, for carrying a duplicate railway line between Fremantle and Perth. Another first in the Colony was achieved on this job: the piles were driven into the sand using the water-jet process with only light assisting blows from the monkey.

The North Mole reached its originally planned length of 2,934 feet on January 31st 1895. By this time it had been determined and approved that extension was desirable and construction was continued to a length of 3,450 feet, which was reached in 29 feet of water. At the end, a bulb 130 feet in diameter was formed and completed in November 1895. The top width at the outer end was 52 feet and at the shore end 30 feet. A further extension of the North Mole from 3,450 feet to 4,800 feet was commenced in July 1899 and completed in December 1902. The outermost portion of this extension was constructed in granite.

In 1902 a layer of armour granite was placed on the north face of the entire length of the mole:

> "During construction of this mole there was considerable loss and waste of the sandstone at the tip-head in stormy weather, the work advancing very slowly in the winter months. In one bad month in 1901 there was a loss equivalent to 2 per cent of the whole contents of the mole between the 3,450 feet to 4,800 feet marks. But, once the stone had settled into position, little occurred. Thus, for 2 years after completion of the parapet, on the original length of 3,450 feet of the North Mole, only some slight flattening of the slopes took place. During the winter of 1898, notwithstanding several severe storms, only 6 per cent of the reserve stone in the parapet was drawn into the sea slope. The expenditure on

repairs was 700 Pounds in 1898-99, and thereafter no further outlay was incurred to December, 1900. It may indeed be said that only the anticipated clawing down of the slopes by the sea occurred, and the extent even of this was moderate....."

The South Mole was completed to the planned length in August 1897 and, during the first five years of service, no repairs were required. In 1902 the extreme end portion of 150 feet was topped and faced with granite in preparation for the permanent light tower.

In the almost one hundred years since the construction of the breakwaters commenced they have given almost maintenance-free service. Gradual losses of armouring on the North Mole have occurred and granite facing stone has been introduced at locations along its now reduced length. Although a severe cyclone caused extensive visual damage in 1978 to the North Mole, it is the only known case when immediate repairs were necessary. For the remainder of the time, both breakwaters have incorporated wide, sealed roadways enjoyed by the public throughout the four seasons of the year.

4.6 The Dredging

In his submissions to the Government O'Connor fought for sufficient initial funds to allow the works to be commenced in an orderly fashion, planned for greatest economy and to meet his promised programme of Royal Mail Steamers into Fremantle within eight years from commencement of construction.

4.6.1 The Bar

In particular, this planning called for commencement of the bar removal as soon as sufficient weather protection could be given to the site by North Mole progress. As an inducement O'Connor advised that his plan called for utilization of the rock from the bar for his breakwaters. While this probably was largely 'tongue in cheek' a certain amount of this rock was incorporated, according to some reports.

Assured funding was essential to allow for the advanced purchase, design and construction of dredges from Europe. At Appendix C, newspaper articles record the public interest in the arrival and employment of plant for the works.

The first item of dredging plant to arrive was the Priestman grab which was imported in parts in August 1893 and assembled in the Colony. It was

launched on April 29th 1894 and was used inside the bar for removing rock which had been shattered by blasting. The bucket dredger 'Fremantle' arrived in October 1894. Assent was given to The Loan Act - 1894 on November 11th which allocated a further 200,000 Pounds for Fremantle Harbour thus allowing continuity of construction.

In addition to the dredges, other essential plant such as barges, cranes and work boats had to be secured, both overseas and locally, within a suitable time frame.

The blasting of the rock bar involved the use of simple effective plant. The conditions were rather exceptional. The shallowness of a large portion of the bar crest precluded the employment of floating drilling craft. Jarrah trestles were made with ladder shaped tops on which were placed broad pine planks about 30 feet long. The four-footed trestles provided stability and the planks could be placed at any height to suit the tide and wave conditions. Boats were able to easily transport the trestles from place to place. Coverage could be obtained of areas up to 250 feet by 80 feet, equivalent to the deck space provided by six to ten of the punts normally used in submarine blasting.

A stage of the area mentioned, carried from 120 to 160 men. Six trestles per day were fabricated of jarrah scantling at the carpenters' yard. The stages were effective in up to 22 feet of water and were used for operating the hand drill and jumper. Holes were put down 8 to 10 feet apart and charged with 12 to 15 lbs. of dynamite or gelignite exploded by fuse or electricity which shattered the mass to such an extent as to render it easily removable by the bucket dredger 'Fremantle'. The charges had to be limited in number to single shots or, occasionally, small groups because of the proximity to the town of Fremantle. The quantity of solid rock drilled and blasted ready for dredging up to June 30th 1895 was 187,394 cubic yards for an expenditure of 24,214 Pounds. The Priestman grab commenced cutting through the rock from inside the bar on March 12th 1895 joining the 'Fremantle' which commenced dredging at the seaward end of the blasted channel on December 17th 1894.

In 1893 an outlandish proposal was put forward to remove the rock bar by underground tunnelling using shafts and galleries. Plan PWD WA 2221 shows the proposal. The advantage was said to be

that 50 to 100 men could work three shifts in the galleries below the water level at wages of 10 shillings per day, unaffected by tidal or wave conditions outside. Rock was to be removed by hand using pick, shovel and small carts. When the overhead rock was thin enough the men would be evacuated and the rock roof collapsed by explosive charges.

As later works were to clearly demonstrate, it was fortunate that O'Connor and his staff did not countenance this alternative - the bar and adjacent reef areas were extremely porous in some areas, including locations with massive cavities. A catastrophe was certainly avoided.

Conversely, some isolated sections of corraline limestone proved extremely hard and expensive to shatter by the hand drilling system and the engineers employed torpedoes to remove them.

The 'Fremantle' cut through the bar and passed into the river on September 13th 1895 followed by the suction dredger 'Premier' in January 1896. The 'Premier' then set to work on the sand in the inner basin. A second bucket dredger, the 'Parmelia', and a second suction dredger the 'Governor', were added to the fleet in 1896 and 1899, all four vessels designed by Coode, Son and Matthews. The bucket dredgers were built in Scotland and the suction dredgers in Holland. The 'Parmelia' was the first dredge in the Colony to be fitted with electric light. This permitted round-the-clock operation which was becoming common overseas in dredging operations. In addition to the above, small suction dredgers the 'Canning' and the 'Perth' were used to excavate under Victoria Quay.

A newspaper report, at Appendix C, indicates the detailed interest in dredging progress, particularly with the opening up of the river, once the bar was removed.

4.6.2 Reclamation Works

The dredging progressed more rapidly once the 'Premier' was operating in the inner harbour and reclamation of the southern shore began to take shape. The general level of fill was fixed at 10 feet above low water on the south side of the harbour and 13 feet on the north side. The filling consisted partly of dredged material and partly of quarry waste brought down in trucks from Rocky Bay:

"It was necessary, therefore to provide a retaining-bank for the dredgings, with openings through which the water could drain out rapidly. The first work, consequently, was the construction of a bank from end to end along the edge of the reclamation-area, 10 feet above water level and 20 feet wide. This bank had also to serve as the formation for an independent railway line for the stone trains from the Rocky Bay quarry to the South Mole and it was so used as soon as the railway bridge across the Swan was completed and the North Mole had reached its intermediate terminus."

"The bank was faced on the harbour side with tipped stone. This would have slipped down as the dredging progressed and a coating would easily have been obtained as on the north side of the harbour, but the work was rendered difficult as the dredging could not be carried out fast enough for the circumstances of the case. Thus orders were issued by the Government at the end of August 1898 to commence wharf construction and by the 30th June 1897 about 1,500 feet of quay was available for use by vessels, though the depth of water alongside was only 20 feet. By the 30th June in the following year the reclamation on the south side was completed, and 4,450 feet of the south quay was available for use but the dredging was not complete adjoining any portion of the quay: the actual conditions were 1,850 feet of wharf with 25 feet depth of water 1,000 feet with 20 feet of water, and 1,600 feet with 12 to 15 feet. The result was that both the material below water and the excess stone above and below water remained badly disposed. . . Matters were improved somewhat by the use of a small suction dredger to excavate under the wharf but only part of the material could thus be moved and it was not possible to employ a more powerful tool for fear of damaging the ground below the sheds and a temporary passenger-station erected adjoining the quay."

"The irregular disposition of the stone was not only a source of expense when the quay, constructed under pressure to accommodate traffic, was widened out to the present width but was also a cause of serious nuisance, as the garbage which collected on the rough surface assisted in furnishing food for colonies of rats that lived in the

> interstices of the stonework; and these rats were a considerable source of danger in times of bubonic plague. In order to obviate these difficulties, the stonework, from the top to as low as the water would permit, was roughly 'napped' to a face and coated with concrete. . ." (10)

Other excerpts from Palmer's paper to the Institution of Civil Engineer's in 1911, give a greater insight into the advantageous use made of the surplus dredged material.

The narrow neck of land on the north side of the river leading to Rous Head was reclaimed for cargo handling use, but its necessarily low level rendered it vulnerable to storm seas. Apart from the rock protection works placed along its boundary, the decision to dispose of the large quantity of surplus dredge material along the seaward boundary greatly reduced wave energy.

The decision also demonstrated O'Connor's complete confidence in his own analysis of sand transportation in the area.

Despite the disposal of over eight million cubic yards there was no subsequent evidence of this material returning to the river-mouth.

Over the years North Quay cargo area has been expanded three times and now constitutes the major port area. This latter-years' reclamation has been considerably assisted and made more economic because of this original decision.

> "On the South the basin is well protected naturally by high ground, but on the North the narrow neck of land, more than once threatened and once breached by the sea, has been widened out, protected on its sea face by stone revetting and provided with an artificial breakwind. On this side of the basin, the widening and reclamation have provided a considerable area of land, and the quay is laid with railway lines connected directly with the railway system of the Colony. On the south side reclamation has also provided a large expanse of land behind the quay, and partly on this ground are situated the sorting sheds for cargo, and behind them the railway sorting yards, in direct communication with the railway goods shed and main station."

"Of the dredging, a small quantity of suitable stone was deposited on the line of the North Mole, and about 3 per cent was pumped by one of the suction dredgers on to the area to be reclaimed, still leaving nearly 9½ million cubic yards to be disposed of. It was decided that the most suitable dumping-ground for the dredges and barges was along, and not far from the shore north of the North Mole. Contours of the ocean bed adjoining the river-mouth taken in 1897 disclosed the proximity of the 2-fathom contour to the shore north of the river. This was dangerous; for a breach, in storms, of the narrow isthmus connecting Rous Head with the mainland had been threatened more than once and had occurred once."

"Dumping of the dredgings was commenced, therefore, near the North Mole and continued farther afield as each patch of ground was rendered too shallow for use. Ultimately the spoil was spread over an area bounded on the south by North Mole, on the west and north by the 3-fathom contour of 1902, on the south-east by the shore (as near, that is, as the dredges and barges could get), and on the north-east by a line in continuation of River Street. Of the whole quantity dredged and deposited in the years 1893-1901 namely 8,321,000 cubic yards, about 63½ per cent remained within the area of deposition, and a further 17 per cent was deposited by the sea outside this area but within the limits of the soundings: of the balance, 113,000 cubic yards, or 1 1/3 per cent went to advance the foreshore, and the remaining 18 per cent was entirely lost. An analysis of the weather conditions in three periods from 1899 to 1901 shows that there was some correspondence between the weather and the percentage of dredgings drawn out to sea and lost to ken. These lost dredgings were not carried to the south of the harbour so far as the soundings showed, for comparison of the 1893 and 1903 contours disclosed the fact that south of the entrance channel there had been practically no change in the ocean bed. Even the patch south-west of the South Mole had remained in the same condition throughout the 10 years."

> "North of the North Mole there have, of course, been changes, the foreshore and the 1-, 2-, 3-, 4-, and 5-fathom contours all having advanced; but this, as already shown, can be ascribed to the sea having moved and distributed the dredgings. Between the surveys of 1902 and 1903 the 5-fathom contour due north of the North Mole advanced markedly, and on the other hand, the survey of 1903 also disclosed that the water opposite the narrow isthmus connecting Rous Head with the mainland was deepening and the foreshore was receding in this locality."

4.7 The Inner Harbour

4.7.1. The Harbour Depth

The depth to be dredged in the basin was significant for any project. Willis Point was up to 6 feet above low water resulting in a total deepening of up to 36 feet to the harbour depth of 30 feet.

The project depth for the harbour was well received by the shipping as a published interview of 1906 indicates:-

> "Captain W. E. Maxwell-Brown, who commands the fine four-masted Houlder liner 'Evertour Grange', which arrived in Port yesterday morning from New York, was spoken to by a 'West Australian' representative . . ."
>
> > "What do you think of Fremantle as a port?"
> >
> > "It is a decidedly good one, because you have 30 ft of water alongside the quay, which is a great convenience. In that respect it is much ahead of Melbourne. This ship could not be alongside any wharf at Melbourne fully loaded."

The significance of the designer's decision in 1891 to dredge the harbour to 30 feet, with provision (or intention) to increase this depth to 36 feet, is also apparent from a paper by T. C. Dub, Engineer-in-Chief, Sydney Harbour Trust in 1911. Of particular interest was a table showing the draughts of the 'twenty longest vessels afloat' for the decades 1881, 1891, 1901.

At the design date for the Fremantle Harbour this average was 27 feet. By 1901 it had grown to 32 feet.

The Fremantle Harbour with 30 feet alongside in 1900 compares interestingly with Sydney in 1911 - where 100 berths had 28 feet or less alongside and 15 newer berths with 32 feet of water at L.W.S.T.

4.7.2 The Wharves

By 1897 the urgency for wharf frontages was met by construction works on three sites simultaneously with a total of nearly 5,000 feet of wharf being constructed for the year. The supply of the large quantity of timber from the South-West forests in the required time also reflected the other engineering works and planning necessary for the successful progress of this project.

The wharves and quays were constructed of timber halfcaps, corbels, beams, and decking on a jarrah pile sub-structure. Piles were spaced at 12 feet centres in each direction. South or Victoria Quay was 62 feet wide, the maximum halfcap length was about 40 feet with splices staggered. Rails were laid proud of the decking. The quay was constructed for a total length of 5,055 feet. On the north side of the harbour 2,000 feet of quay was built and a projecting jetty or finger pier. It was intended to be used by mail steamers as it was feared that vessels moored at Victoria Quay might not be able to get away safely to time in spells of bad weather. This did not prove to be a problem, the mail steamers always berthed at Victoria Quay except at times of bubonic plague when they remained at moorings in the centre of the harbour.

Because of the great rush of traffic to the Colony in the 1890s wharves were also built alongside the moles, 1,000 feet on the north side and 300 feet on the south. The jarrah piles, no doubt with a cast iron and steel shoe attached, were actually driven through the limestone of the moles.

Details of the North Mole wharf and the first employment of steam pile-hammers are provided by newspaper reports, at Appendix D.

4.7.3 The Turning Basin

The harbour basin as then designed by O'Connor was 800 feet in width. As it would be fully sheltered and exposed to practically no inconvenience from tide or river currents, he believed it to be ample at that time, but he was not finally committed to this width. O'Connor possessed an acute awareness of changes in shipping.

> "There is no objection from an engineering point of view to (the basin) being wider than 800 feet . . . a greater width of basin has been urged by persons who take a deep interest in the matter and some of whose opinions are based on considerable seafaring experience."

He expressed his readiness to increase the width of the basin when the government authorised the additional expenditure. As the north side of the river basin would probably be the last portion of the works to be completed, this would allow him flexibility in development. In his annual report for 1897-98 O'Connor stated 'a sufficient space will . . . be provided in the inner basin for the longest steamer trading to Australia to swing in.' In the following year a vessel of 10,769 tons, a steamer of the North German Lloyd Imperial line, the S.S. Barbarossa, entered the harbour and turned in the basin, at that time dredged to a width of 650 feet. Later, when the first of a proposed series of jetties for mail steamers was constructed from the north side of the harbour, the width of the inner basin was increased to 1,400 feet.

4.8 Auxiliary Works

A number of minor works were undertaken in conjunction with the main Fremantle Harbour development. One of these was the Rous Head 'temporary' slipway which provided Fremantle's main docking facility for nearly fifty years. The slipway accommodated vessels up to a maximum of 650 tons slipping displacement and a maximum keel length of 160 feet on an incline of 1 in 24.

Any of the four dredges could be accommodated in addition to most of the coasters. When the slipway was demolished in the late 1950's some components of its hauling machinery were incorporated into the new 600 ton slipway at Arthur Head.

A breakwind was also erected to protect the harbour basin from north-west gales. It extended 2,200 feet eastwards from the root of the North Mole and consisted of a roughly dressed dry sandstone wall surmounted by an open timber fence reaching 45 feet above low-water level.

The five lights connected with the harbour were all obtained under the advice of Mr. W. T. Douglass, M.INST.C.E. The main light, situated on Rottnest Island, was installed on a stone tower 204 feet above sea-level at the focal plane. It flashes every 20 seconds. The second light, which enabled Rottnest Island to be safely cleared was situated at Bathurst Point. It is 98 feet above low water. The third, or Woodman's Point light, 126 feet above low water, directed vessels up Gage Roads until they reached the harbour entrance, where, at the end of each mole was placed a cast iron tower 20 feet high, carrying fixed lights.

4.9 Mail Steamer Provisions

Whatever services the port was able to provide for the newcomers, Forrest's objective - to make Fremantle a mail station - was never out of his mind. "No scheme of harbour works will be complete without the mail steamers," he had told guests at the inauguration ceremony in 1892. His anxiety to achieve that end made him the victim of every adverse opinion expressed on the harbour. In November 1894 he sought reassurance from O'Connor. In the Assembly the Speaker, a large landholder and leading settler in the Colony since 1860, had expressed the opinion: "If this work were to be carried out according to the original plan . . . no large ocean steamer, coming here to make short stay, would ever jeopardise herself by entering that harbour." Perhaps the Premier was doubly impressed by the fact that thirty-five years earlier, the Speaker had seen fifteen years service at sea, four of them as commander of the East Indiaman, the 'Devonshire'. So the Premier now demanded assurance from the Minister:-

> "Do I understand distinctly that the harbour as designed will provide accommodation inside for the P & O and Orient steamers, at all times and in all weathers? If the proposed harbour will not do this I shall not be satisfied, and in that case, but not otherwise, an outer anchorage will require to be provided."

He professed himself as satisfied to accept O'Connor's opinion.

O'Connor's reply was unequivocal. "I have no doubt at all that the harbour works as at present designed will, when completed, provide complete accommodation inside for P & O and Orient steamers, at all times and in all weathers." Characteristically he then commented directly on the suggestion put forward by the Speaker of the Assembly proposing an extension of the North Mole with the provision of a cant in order to provide an outer anchorage. These O'Connor showed, would not be necessary; such work would cost at least 500,000 Pounds and would take at least ten years to complete.

In August 1898 the SS Giera, of North German Lloyd Imperial line, berthed inside the harbour following an announcement of that Company that they would switch to Fremantle from Albany. The move was successful but the cautious British companies still required additional harbour improvements. As work on the north side of the harbour was incomplete, a dogleg in the alignment of the north quay resulted in an increase in the width of the main basin to 1,400 feet. This width was maintained over a distance of 2,850 feet with a depth of 30 feet at low water. At last the British companies were satisfied and the substitution of Fremantle for Albany seemed a formality.

However there was not only anger and despair in Albany at the projected change, but anger, at least in Sydney and Melbourne because the slightly longer route increased the scheduled time for the journey by twelve hours. Forrest rightly pointed out that the twelve hours extra delay was only a safety margin and that the mail carriers had undertaken to maintain the existing schedule. He further threatened that the stand by Victoria, in particular, could well prejudice Western Australia's attitude towards joining the forthcoming federation of Australian colonies.

Forrest won the day and on August 3rd 1900 the Postmaster General in London advised that Fremantle would henceforth be substituted for Albany as the Western Australian port for the mail steamers.

On August 13th 1900 the R.M.S. Ormuz was the first British mail carrier to enter the new harbour. The local excitement was considerable and The Western Mail of August 18th describes the event accordingly:

> "A quarter past 9 O'Clock on Monday night saw the consummation of the work begun in November, 1892, for the purpose of converting Fremantle into a harbour worthy of the chief port of the Colony. At that moment the Orient liner Ormuz was berthed alongside the South Quay, and the aim and desire of the Premier and the Engineer-in-Chief had been

achieved - the harbour of Fremantle was accommodating a British mail steamer. A dense crowd of people was on the wharf to witness what will be an historic event, and, as the steamer's gangway was lowered to touch the quay, hearty cheers were raised. It had been hoped, and even calculated, that the 'Ormuz' would reach Fremantle during the middle hours of the afternoon, but when the report came through from Albany on Sunday night that the vessel had only passed Breaksea Island at 7 p.m. it was seen that, upon the basis of her average speed, she would not arrive at Fremantle much before 7 O'Clock at night. Universal disappointment was felt at the fact that her appearance would not be a daylight one, because thousands of people in Perth and Fremantle had determined to witness the interesting spectacle. The signal staff at Fremantle just after 3 O'Clock indicated that a steamer was passing northwards, having been sighted at five minutes to 3, 35 miles away from Rottnest. It was at once concluded that the vessel was the 'Ormuz' and the guess proved correct. Shortly afterwards people began to collect on the wharf and from thence onwards the crowd grew . . .

The Premier (Sir John Forrest), in proposing the toast of 'The Orient and P & O line of Steamers' said it was a very pleasant duty and a great honour that had been conferred on him that night in proposing success to the Orient and P & O Companies. Those Companies were very old friends of theirs (Hear Hear). They had known them for many years. Most of those present had had the pleasure of travelling by those steamers and he thought that there were few, if any, who had not a good word to say for both the two splendid companies.

Before concluding, the Premier paid a tribute to Mr. C. Y. O'Connor, whose health was proposed by Sir George Shenton. The Engineer-in-Chief, in reply to the toast, reminded them that in November 1892, he had undertaken to have the harbour so far advanced at the end of 8 years as to permit of the entrance of the largest steamer. The eight years had not yet expired and his promise was already fulfilled."

5.0 PROJECT COSTS

Various records of annual and total costs have been examined. However, with a project extending over an initial eight and ten year period, these records are easily misinterpreted. The changes made to the project's parameters and, indeed, the continuous expenditure on further works after the initial period, also make establishment of an account point rather imprecise.

The most satisfactory way to report on the project then is to present data from one source only. Palmer's paper has been chosen as a suitable summary of the costs as it conveys some engineering dissection of the cost rates and apportionments.

DETAILS OF COST

Almost the whole of the work was carried out departmentally and from the detailed accounts kept of expenditure and of work done the following particulars have been abstracted regarding the excavation of the channel and basin, which is divisible into two parts: first, the drilling and blasting of the rock, and secondly the dredging.

It was essential that drilling and blasting should be started quickly and pressed on with: to obtain special plant from Europe would have meant delay, and floating drilling-craft could not be satisfactorily employed, owing to the shallowness of the waters over a large portion of the bar-crest and other parts: moreover this rock was soft enough for the hand-drill which was therefore employed and worked from the stages. A ton of explosive sufficed for about 5,600 cubic yards of rock blasted. The expenditure on the various sub-heads of the work varied from time to time within limits, but approximately the total cost can be subdivided thus:

Stages and other plant	16 per cent
Placing stages	6 per cent
Tugs, punts, pumping, etc.	4 per cent
Repairs to various plant	4 per cent
Stores, piping, drills and other tools	6 per cent
Explosives and blasting	16 per cent
Drilling	48 per cent
TOTAL	100

The material dredged consisted, in various parts, of rock, blasted and unblasted, and of clay and sand; most of the sand was removed by the suction dredgers, but large quantities were excavated by the bucket dredgers, partly where it was too compact for removal by the former, and partly when time pressed and it was necessary to clear particular areas quickly for commercial purposes. There were also large masses of weeds which clogged and hampered

the dredgers and had to be specially dealt with. About 42 per cent of the whole was removed by the bucket dredgers.

The whole cost of the dredging can be subdivided thus:-

Depreciation of plant	20½ per cent
Working of the dredges	69½ per cent
Soundings, salaries of temporary staff, etc.	7½ per cent
Incidentals	2½ per cent
TOTAL	100

The work of the bucket dredgers was too diversified for preparation of any complete subdivision of the whole cost of dredging by them; but the following Table shows the costs at Fremantle for the suction dredgers:-

	Dredge "Governor"	Dredge "Premier"	
Period in which dredging effected	17/1/1900 to 30/3/1900	29/6/1898 to 27/6/1899	3/7/1900 to 2/7/1901
Volume removed in period Cubic Yards	221,785	720,377	801,059
Time dredge delayed in Period:-			
For repairs . . . Hours	135	590	408
By bad weather. . Hours	5	332	410
By other causes . Hours	53½	76	241
Total hours delayed	193½	998	1,059
Ratio of delays to whole working time . . per cent	13	13	14
Volume dredged per hour of actual time worked Cubic Yards	171	111	124
Items of Expenditure	**Rate per Cubic Yard**		
	Pence	Pence	Pence
On salaries	0.19	0.34	0.24
On wages of crew	1.23	1.59	1.41
On coaling	0.08	0.10	0.08
On watering	0.02	0.04	0.04
On coals	0.71	0.60	0.64
On stores	0.06	0.08	0.06
On miscellaneous	0.16	0.18	0.23
On repairs and renewals	0.59	1.03	0.94
On workshops, supervision, etc.	0.14	0.28	0.19
TOTAL	3.18	4.24	3.83

The total cost of the final scheme up to 1903 amounted to 1,458,940 Pounds, distributed as follows:-

DETAILED COST OF HARBOUR WORKS

	Pounds	Pounds
North Mole:		
To 3,450 feet - 612,700 cubic yards	135,367	
From 3,450 feet to 4,800 feet - 394,378 cubic yards	142,747	
South Mole:		
To 2,040 feet - 254,196 cubic yards	70,958	
	-------	349,072
Wharves:		
On North Mole 1,000 feet long - 51,285 square feet	14,419	
On South Mole 300 feet long - 14,604 square feet	4,992	
Victoria Quay 5,077 feet long - 296,136 square feet	122,686	
North Quay 1,978 feet long - 150,937 square feet	45,173	
Mail boat jetty, 450 feet long - 55,350 square feet	21,726	
	-------	208,996
Reclamation:		
North side of river - 22 acres	22,865	
South side of river - 54 acres	27,312	
	-------	50,177
Dredging:		
Drilling and blasting - 1,503,099 cubic yards	238,345	
Dredging - 9,637,501 cubic yards	455,298	
	-------	693,643
Contingencies:		
Breakwind - 2,128 lineal feet	6,302	
Moorings	5,351	
Slipway, with cradle 185 feet long for dredges and other vessels up to 650 tons dead weight	21,644	
Office, etc.	4,566	
Land purchase	6,836	
Petty items	7,383	
	-------	52,082
TOTAL		1,353,970

In addition, expenditure has been incurred on:-

Jetties in open harbour:

Main sea jetty	70,960	
Fremantle South	913	
Owen Anchorage, for explosives & stock	3,842	
Woodman's Point, for quarantine station	721	
	-------	76,436

Lighthouses:

Rottnest main	9,276	
Rottnest eastern	3,114	
Rottnest keepers' etc., quarters	1,619	
Woodman's Point	7,646	
South Mole	2,254	
North Mole, temporary	147	
Cable, mainland to Rottnest Island	4,478	
	-------	28,534
GRAND TOTAL	Pounds	1,458,940

6.0 EARLY COMMERCIAL RESULTS

The expenditure for constructing a protected harbour for the main port of the Colony was easily justified - the survival of trade to the Colony's Capital.

The resulting efficiency, however, enabled the port to achieve an operating profit from its earliest years.

> "It is evident from this brief history of events during construction that the harbour was a great commercial necessity. This conclusion is emphasized by the facts that whereas in 1894 the whole tonnage of vessels visiting Fremantle was 337,820 tons (ie. 406 vessels of an average net register of 832 tons), the corresponding figure in 1902 was 1,322,584 tons (657 vessels of an average of 2013 tons), and in 1905 it was 1,462,995 tons (797 vessels of an average of 1,835 tons). This trade could not have been accommodated at all at the old outer jetty, on account of both its volume and the large size and deep draught of much of the shipping.
>
> Financially too, there has been a great saving, for the previous cost of handling, both from the jetty and through lighters, was excessive, whereas the charges in the new harbour are moderate, especially in view of the high wages paid in Western Australia. These charges consist in the main, of three items: tonnage, berthage, and wharfage. The first, both inwards and outwards, is 3d. per ton on the registered tonnage of the ship or, alternatively on the cargo, if this is less than one-fourth of the net registered tonnage. The berthage is 2d. per ton on the cargo, with a minimum of 5s. and a maximum of 20 Pounds; and the wharfage is 2s. per ton on the cargo landed.
>
> The net earnings of the harbour were 48,023 Pounds in 1903, 50,238 Pounds in 1904 and 52,511 Pounds in 1905, which on the inwards cargo only amounts to 1s. 4d. per ton. This may be contrasted with the profits of the old-established harbour of Melbourne, where the net earnings in 1901 and 1902 averaged 1s. per ton, calculated on a fourfold volume, 2,822,000 tons, of combined inward and outward cargo. Looked at in another way, the financial results are also satisfactory, for the average interest on Western Australian Government loans was 3.41 per cent, and on this basis the annual interest on 1,353,970 Pounds the cost of the harbour-works, is 46,170 Pounds per annum or, in round numbers 2,000 Pounds less than the net revenue in 1903. The harbour is therefore one of economical design: moreover, at moderate expense it can be made to accommodate 50 per cent more shipping than in 1904-5 and there does not seem any doubt that, on increase accordingly of the traffic and endowment

of the harbour with storage-facilities, the port charges could be so reduced as to lower the incidence of the net earnings from the present 1s. 4d. per ton to 8d. per ton, calculated on the inward cargo only."

APPENDIX A

'MORNING HERALD'
August 15th 1890

THE FREMANTLE BLOCK

DEPUTATION TO THE COMMISSIONER FOR RAILWAYS

THE GOVERNMENT PROPOSALS

A deputation from Perth and Fremantle Chambers of Commerce, the Fremantle branch of the Australasian Steamship Owners' Association, and merchants of the City and the Port, waited on the Commissioner for Railways yesterday to lay before him certain resolutions, concerning the block at Fremantle, which were recently passed at a conference of representatives of the Perth and Fremantle Chambers of Commerce. There were present - Messrs. G Randell MLA, A B Kisdon MLC, J J Higham MLA, H Briggs MLC, E Solomon MLA, M L Moss MLA, J Hurst, P C H Campell, J M Ferguson, J M H Clarke, R J Willshire, B Gray, W E Moxon, W Le Couteur, C M Newman, J Cowen, E C Shenton, G H Lissimer, W G Wison, F Wilson, and Captain Laurie. The Engineer-in-Chief, the General Traffic Manager and the Secretary for Railways were also present.

Mr Randell, in introducing the deputation, said that those present desired to submit to the Commissioner the resolutions passed at the conference of the Fremantle and Perth Chambers of Commerce. He was sure that the deputation had not come with any hostile feeling towards the Department or the head of it but with a view of assisting it, if possible, with suggestions which would enable the block to be removed. (Hear, hear) Letters had appeared in the papers, which, perhaps had gone to extremes in references to the question, but after making due allowance for the feeling aroused by the delays which had occurred, he would see that there was a large substratum of truth underlying the statements made. He was entirely in sympathy with the idea of opening up the river on the south side, and he thought that, if this were done it would have a very considerable influence in accelerating the discharge of vessels. Possibly also, the Department might lessen the existing trouble if it would make temporary arrangements on the northern side of the river for discharging Government cargo such as rails and cargo.

'MORNING HERALD'
August 15th 1896

SHIPMASTERS' MEETING

The masters of vessels lying off Fremantle have decided to hold a meeting at the Sailors' Rest, Fremantle, at 2 p.m., on Monday, for the purpose of discussing the "block" question, as far as it affects the sailing vessels and the English steamers. The captains have resolved to call in legal assistance to ascertain whether or not they can lawfully claim damages for detention.

'WEST AUSTRALIAN'
September 26th 1896

THE FREMANTLE BLOCK

RELIEVING THE CONGESTION

It is now barely six weeks since the outcry was raised at the Port that the block in the shipping trade was becoming intensified every day through the incapability of the Railway Department to deal with the very large quantities of cargo arriving at Fremantle. Though there was no question as to the existence of the block then, a transformation in the state of affairs is now being rapidly effected, and in the course of another month or two it is confidently anticipated by Mr Douglas the Piermaster, that the block will be a matter only of history. During the past couple of months a steady stream of cargo has been pouring into the Port, but through the untiring energy of the Railway Department which has concentrated its whole attention towards relieving the congestion, a vast improvement in the position of affairs is shown today on that of a couple of months back. At present there is only one intercolonial steamer awaiting a berth at the jetty, and she will be able to come alongside today the English steamer Maori King being aimed to leave for the East this afternoon. The latter vessel took up a berth at the jetty eleven days ago and that she has had very fair despatch is evidenced by the fact that she has put out on an average 235 tons of rails per day. With regard to the sailing fleet, the majority of them have almost completed discharging operations, and Mr Douglas feels sure that at the present time there are not more than 3,000 tons of cargo in the whole of the sailing vessels in the harbour. Men are kept working in the sheds every night until 10 and 11 o'clock unloading trucks in order to have them free for jetty traffic first thing in the morning.

The berthage accommodation is at present the chief difficulty under which the Department labours, but in less than two months, Mr. Price, the contractor for the extension, expects to have his work completed. This will give accommodation for two additional steamers on either side, and within nine months, it is anticipated that three large steamers will be able to take up discharging berths at the wharf now being constructed inside the river on the south side. To meet the increased demand which will thus arise for storage accommodation, a large shed 500 feet by 64 feet is being erected on the reclaimed land on the northern side of Arthur Head.

APPENDIX B

'MORNING HERALD'
October 23rd 1896

FREMANTLE HARBOUR WORKS

A PARLIAMENTARY INSPECTION

Most of the members of the two branches of the Legislature have at various times sanctioned the expenditure of large sums of money for the Fremantle harbor works, and in order to let these gentlemen have an opportunity of inspecting the work for which they were practically responsible, the Director of Public Works issued invitations for them to visit Fremantle and inspect the works. The trip took place yesterday, and notwithstanding the extremely boisterous nature of the weather at about midday, a large number of gentlemen assembled at the William Street jetty at 1 o'clock in order to board the River Company's steamer 'Gareenup' and make a river trip to Fremantle. Among those present were the Premier, the Director of Public Works, Sir George Shenton, Sir James G Lee Steere, and Messrs. F M Stone MLC, F T Crowder MLC, R S Haynes MLC, J Howard Taylor MLC, R F Sholl MLA, G Randle MLA, E Solomon MLA, G Throsell MLA, G T Simpson MLA, J Cookworthy MLA, C Harper MLA, F C Monger MLA, J J Higham MLA, S J Phillips MLA, the Engineer-in-Chief, the General Traffic Manager, Bishop Salvado, and Messrs A D Bell, M E Jull, C J Lee Steere, W A Gale Cook, H F Turner and Padbury.

The moorings were cast off at about 1.30 and the steamer started her course against a very stiff south-westerly breeze, which made the water very choppy, and caused the progress of the vessel to be somewhat slow. Mr Piesse had spared no pains to enable his guests to spend a pleasant time, and the vessel had been specially prepared for the occasion. The whole of it was covered with an awning, while bunting and palm leaves gave the steamer quite a festive appearance. A long table and seats had been erected on the deck, and as soon as the vessel was clear away from the jetty the guests sat down to an excellent luncheon provided by the Parliamentary caterer. The wind and slight rain squalls had a somewhat harassing effect on those exposed to them, and blew the crockery about somewhat, but small trials of this kind were soon overcome, and the luncheon was thoroughly enjoyed. Half a gale of wind was blowing across Melville Water and Freshwater Bay, and no one was particularly sorry when Rocky Bay, near Fremantle, hove in sight. A landing was effected here and a short inspection was made of the enormous quarries which have been made in extracting stone wherewith to construct the North Mole and at work quarrying great boulders of stone, placing them on trucks, and sending them away to the works. A train was in readiness at the quarries, and the visitors were then conveyed by rail straight on to the North Mole. The short train journey was spent in an interesting manner by the examination of plans of the harbor works, thoughtfully provided by Mr A D Bell.

As the engine steamed along the North Mole one could not help but admire the extensiveness and solidity of the work. On each side of the mole the huge seas chasing one another in from the Indian Ocean dashed with terrific force against the enormous boulders forming the basis of the mole, and causing the spray to rise almost over the breakwater. It was an ideal day for an examination of the works, because their usefulness was so well exemplified. It is from the north side that the heaviest weather is experienced, and the sea on that side of the breakwater was very rough. Inside, however, and notwithstanding the fact that the wind was blowing about west-south-west, the water was comparatively smooth, and formed a perfect haven of refuge for any vessel, and a safe anchorage for those ships desiring to work while the gale was spending itself outside.

The chief works consist of two long tongues, one jutting out from each side of the river's mouth, and presenting a convex surface to the river. This is done for the purpose of their acting as breakwaters to the northeastern and southwestern seas. The North Mole, which is now practically completed, has a length of about 3,400 ft. and the South Mole about 2,000 ft. Both moles present a lively appearance, men being engaged at them either in discharging trucks of stone, or in constructing wharves. There is to be one of these latter on each mole, and the work on them is progressing rapidly and effectively. On looking at the works, one could not doubt for an instant that the time was not far distant when the large vessels would come alongside these wharves, and complete their discharging operations there instead of adopting the hazardous plan of unloading alongside the present jetty.

In order to enable these wharves to be used, channels had to be dredged, and two or three dredges are now at work in this direction. The works include the dredging of a channel to a depth of 30 ft. below low water, and having a width of from 450 ft. to 1,200 ft. for a total length of about 4,000 ft. The dredge 'Premier', besides doing this work of making a channel, is engaged reclaiming a quantity of land. As the sand pump forces the sand and water out of the river it is pumped through pipes on to a large piece of land between the South Mole and the main railway line, near the East Fremantle station. The sand settles down and the water is drained off, and the land is there. Another branch of the work is the blasting away of the bar at the mouth of the river. This work is being done very cheaply, rapidly, and effectively. There are about 1,000,000 cubic yards of stone to be removed to provide the required 30 ft. of water, and of these about 420,000 cubic yards have been blasted. The dredge 'Fremantle', is near this spot, and clears away the debris after the blasting has taken place. The whole work is being carried on most effectively, and the visitors all expressed their gratification at the possibilities for the shipping trade, and at the seeming success of the undertaking. The visit to the works was a profitable and interesting one to

all concerned. Before the visitors left, the process of pile-driving for the construction of the wharves was explained, and it was ascertained that this was not done by the absolute force of the pile-drivers, but through the medium of a water jet, which cleared a hole into which the pile went, and caused the sand to assume quicksilver like propensities.

After a pleasant hour's examination of the works a return was made to Rocky Bay, and the steamer was again boarded. The return river trip was delightful, for the winds and waves had gone down and comparative peace reigned. Afternoon tea was served on board, and the city was reached shortly after 6 o'clock.

APPENDIX C

REPORTS ON CONSTRUCTION

'West Australian' - September 25th 1896

The new hopper dredge 'Parmelia', recently constructed on the Clyde to the order of the West Australian Government at a cost of about 20,000 Pounds, is now due at the Port. She left Glasgow on July 15th, and latest advices record her arrival at Aden on August 17th. On her arrival at Fremantle the 'Parmelia' will be put to work at excavating the river basin in connection with the harbour works.

'Morning Herald' - October 5th 1896

NEW DREDGE FOR FREMANTLE - Yesterday morning the new hopper dredge 'Parmelia', recently built at Glasgow on the Clyde, to the order of the Government of Western Australia, arrived at Fremantle after a voyage of 78 days. The 'Parmelia' has been constructed on lines similar to those of the dredge 'Premier' at present working on the Swan River in connection with the harbor works. Her dimensions are:- Length, 160 ft.; breadth, 34 ft.; and depth 12 ft. 6 in. Her hopper compartments have a joint capacity of 450 tons of dredging, and her buckets a capacity of nine cubic feet each. She is fitted to dredge to a depth of 35 ft. under the water level, when light. The vessel is subdivided into eight compartments. She has lifting gear of the most modern pattern, capable of being worked by steam or hand, bunkers sufficiently large to contain 40 tons of coal, and a mean draught of 10 ft. when fully laden, and 7 ft. when empty. Her engines are sufficiently powerful to draw her at a speed of seven and a half knots, and suitable quarters have been provided for the officers and crew. The 'Parmelia' will commence work in the river at Fremantle with the other dredges now engaged there.

'Morning Herald' - October 8th 1896

Dredging - The dredge 'Parmelia', which is now being dismantled, will be ready for work in about a month. All her machinery is to be overhauled, and everything put in proper order. She is now at the harbor works jetty. The dredge 'Premier' is doing excellent work in dredging a channel to the jetty in the river. The water is deepening rapidly, and there is no doubt about the jetty being ready for use in the contract time, about six weeks hence.

'West Australian' - October 3rd 1896

OPENING THE RIVER

Each month sees substantial progress made with the Fremantle harbour works scheme. Since the completion of the north breakwater a few months back work has been concentrated upon the opening of the channel in the river, the finishing off of the south breakwater, and the reclamation of a large area of land along the south bank, extending from the railway bridge to Arthur Head. One section of the work is hardly completed when another follows in its train, and the progress is so marked that the transformation is at times bewildering. The dredging operations have been extensive, and now a fine deep channel exists from the sea to the old river jetty near the railway station. The material taken from this channel has been almost all solid rock, mixed with the characteristic coralline and silicious formation of the river bar. This work has been done by the powerful bucket steam dredge 'Fremantle'. The channel, so far as it has been made, forms a very small portion of the ultimate waterway in the river. It is now 200 feet wide at its inner end and 250 feet at the seaward limit, the entire length of the dredged portion being about 3,000 feet. The whole of the channel has a uniform depth of 15 feet, which would even now allow of the entry of small vessels to the river. The construction of the south quay wharf has been commenced, and the piling has advanced down the side of the new channel a distance of 150 feet. This section of the wharf is to be 1,000 feet long and 84 feet wide, and will be readily accessible from the adjacent railway yards. The pile-driving is being expeditiously carried on by means of a steam driven plant specially imported by the Government for the work. At present the piling is driven into the sand to a depth of 46 feet 9 inches, and the driving is made easy by the application of forced water jets, which keep the sand loose at the pile points as they are being driven. The proposed depth of the channel along this wharf, when completed, is 30 feet, and the scheme of the south quay wharfage, it is intended, shall extend up the river to about three times the length of the section now in hand. It is expected that over 200 feet of this wharf will be completed in three months from the time of starting, or in about six weeks from now; and the total length of the section, it is anticipated, will be completed within nine months.

'Morning Herald' - November 24th 1896

FREMANTLE HARBOUR WORKS

RAPID PROGRESS WITHIN THE RIVER

THE WORK PROCEEDING DAY AND NIGHT

Within the past two months a great amount of development has taken place in the scheme of harbour construction at Fremantle. Four years ago the work of removing the natural barrier to navigation within the river was inaugurated by the tipping of the first truck of stone intended to form that structure now completed, and known as the north breakwater, the principal protector of the entrance to the river from the sea. During the construction of this section of the scheme it was subjected to the trials of more than one of the fierce north-west gales, and bore the onslaughts without giving signs of weakness. The work of strengthening the great north wall of stone still proceeds, and will, it is expected, be completed in a few weeks time. Another preliminary was the south protecting arm of stone, which has also been completed, and which runs from Arthur Head seaward 2,000 ft.. But the greater developments are at the present taking place in the river itself. It is not, perhaps, generally known that the bar is a thing of the past. Little now remains to be seen of the bank of rock, which sternly forbade the shipmaster to do more than contemplate the line of ocean beach. Indeed fully one-third of the width of the Swan River bar has been replaced by a fine channel of water 15 feet in depth and from 200 feet to 300 feet in width. It must be apparent to an "un-engineering" mind that great results have been obtained from the system adopted of shattering the bar and the work of the dredges built to the order of the Government engineers. A little to the north of the centre of the outer part of the river mouth the rock dredge 'Fremantle' has excavated a channel which runs for a distance of 1,500 feet inward and which ranges in depth from 20 to 12 feet as it proceeds up the river. Another channel is also open a little to the southward, and the two converge at their inner ends. The dredging of a third channel will widen and deepen the southern river to the locality in which the new south quay wharves are being built. The latter are parallel to the railway station. All sections of the scheme appear to be going on with such regard for the necessities of the Port and the Country that it is safe to say one will not have a wait for the other. The estimate given by Mr McDonald, the able and courteous Executive Engineer of the Harbour Works, is that dating from the 28th August last he would provide 200 ft. of permanent wharfage on the south quay, with a channel dredged to a depth of 12 ft., within three months. This has been more than realised and the wharf is being extended at the rate of 15 ft. per day. It was also estimated that in five months from the date mentioned a length of 500 ft. of wharf would be ready for the use in the river, of lighters only, and that within 12 months 1,000 ft. of wharf would be completed

simultaneously with the finishing of a dredged channel from 170 ft. to 200 ft. wide, extending from the rocky bar to the wharf and giving 20 ft. draught of low water. Mr McDonald has so far found that the work has proceeded so expeditiously that he hopes to fulfil the promised work well within the time. This is especially likely as regards the construction of the wharves, the first 1,000 ft. of which will lie midway between Willis's Point and the old river jetty. By the 28th of this month it is anticipated that 300 ft. of this wharf or 19 acres, about one-third of the filling material, which amounted to 296,000 yards, will have been pumped from the river bed by the dredge 'Premier'. At the first, this pumping system cost 1s. a yard but since the huge suction pipe of the dredge has been lengthened, and better facilities thereby given to get into the sand ahead of her, the cost for a time has been as low as 7d. and 5d. a yard. It must be remembered that the pump dredge lifts its own material, carries it to its destination and levels it. The whole of the reclamation work between the railway station and Arthur Head will, it is expected, be finished in five weeks time, and in the meantime the sand is being more economically taken out of the river from the locality at present being dredged than to pump it to East Fremantle. The total quantity of shattered rock removed from the river by the dredge 'Fremantle' up to the present is about 250,000 yards and the quantity blasted is put down at 440,000 yards, so it will be seen that the dredge has a good working face in front of her, so far as quantity is concerned. The dredge 'Premier' has up to the present pumped over 130,000 yards of sand from the river bed, which has mostly been transferred, as stated, to the reclaimed south shore, which has now been raised to 11 ft. above its former level.

APPENDIX D

REPORTS ON PILING

'Morning Herald' - October 17th 1896

THE WHARF ON THE NORTH MOLE - The wharf which was started some time ago on the North Mole of the Fremantle harbor works is slowly assuming a substantial appearance. Up to the present time a length of 100 ft. of piling has been driven, and a number of the waling-pieces fixed and bolted. One of the difficulties which the contractor, Mr M Dowell, has had to contend with is the delay in getting the piles forward. The wharf requires piles of from 48 ft. to 60 ft. in length, and in order to bring the longest of these up from Drakesbrook and Parkerville, where the whole lot has been cut for months past, sets consisting of five trucks each are necessary. These sets can bring only four logs each so that the trouble of getting the long piles on to the work is considerable. There are at present fifteen hands engaged on the contract, but within another week or two Mr Barrett, who has charge of the work anticipates that he will be enabled to employ a large number of men. There has been so far room to work only one pile-driver, but as soon as a temporary decking is laid down two additional machines will start operations. The piles are being driven to a depth of about 15 ft.. The intention is to make a wharf 1,000 ft. in length, giving draught at low water of 28 ft., at the sea end, and 26 ft. at the shore end. Mr Barrett states that given proper facilities, the whole of the pile-driving should be completed by the end of January next, and the rest of the work brought well forward also by that time. A good supply of sawn timber is already on the job. The difficulty in getting piles, however, threatens to seriously impede the progress of the work.

'Morning Herald' - November 26th 1896

TWO STEAM MONKEYS - In connection with the erection of the new river wharf at Fremantle two pile-driving machines which are somewhat of a novelty in Western Australia are being used. These machines (Lacour's patent direct acting steam pile-drivers) were specially imported from England by the Government for use at the Port. The feature of the appliances is the manner in which the monkeys are worked. Instead of by the usual winch and winding gear, which necessitates too much loss of time, the lifting process is performed by the direct action of steam conveyed from the engine by strong india-rubber tubing. The monkey weighs in all two tons, and consists of two pieces - a cylinder and an outside shell. The cylinder remains stationary on the pile-head, while the shell rises for the blow in response to the steam pressure, the drop limit being 9 ft.. With each of these machines five piles per day are being driven to a depth of 47 ft. each, a result which could never be achieved with the pile-drivers hitherto in use here. One machine has been in use on the harbor works for some six months, while the other has but recently been set up. The former has

its engine on a punt in the water alongside; whereas the latter has the whole of its appliances fitted on a skeleton traverser resting on the wharf. The pile-driver lies on a cross set of rails on the traverser, and it is thus easily moved across the wharf according as the piles are being run down. The traverser rests on rollers, and always overlaps the work by about 15 ft. with the greatest ease and with a loss of but a few minutes of time.

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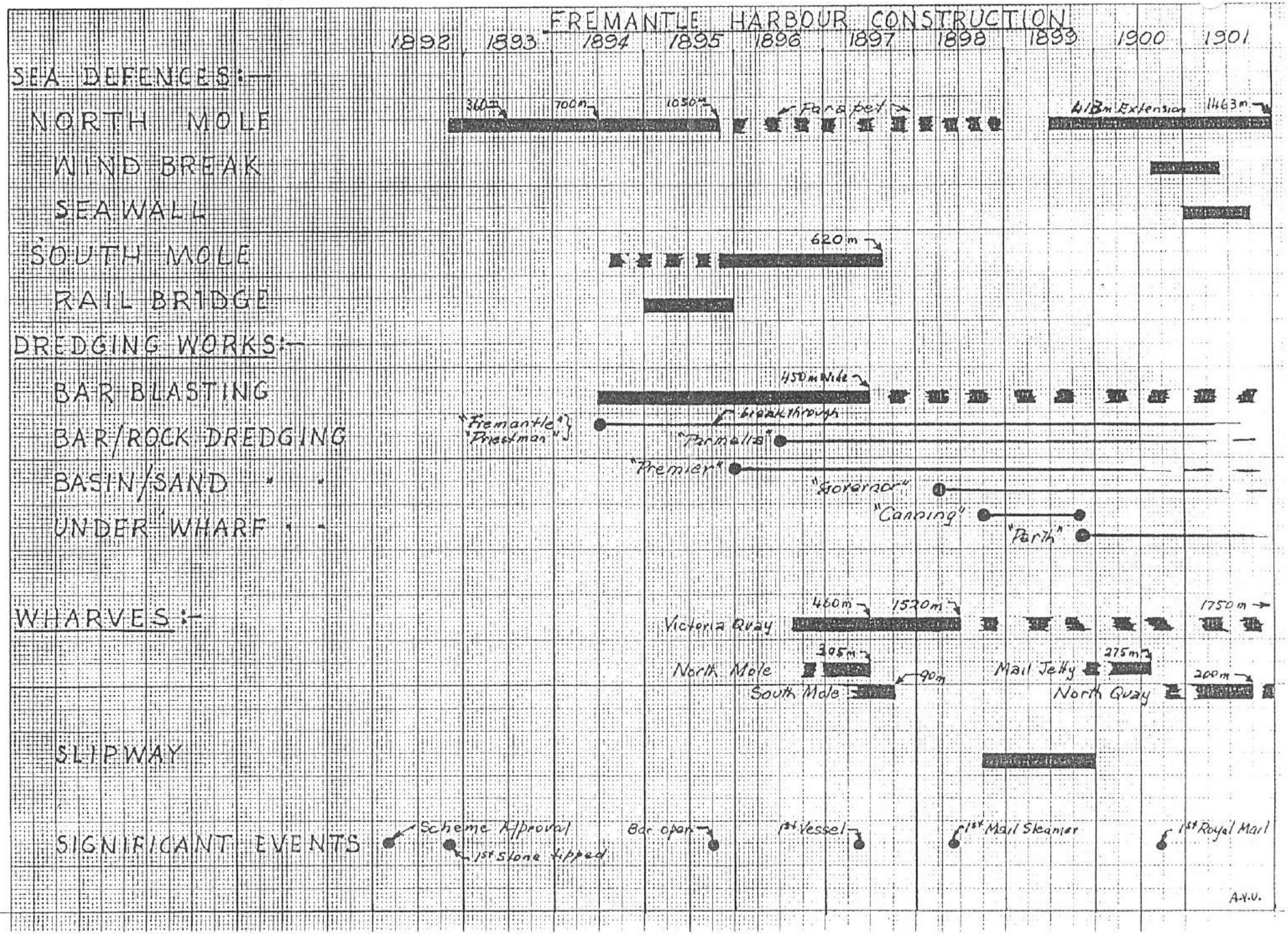

FREMANTLE HARBOUR CONSTRUCTION
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
SEA DEFENCES:-
NORTH MOLE
360
700m
1050m
Parapet
418m Extension
1463m
WIND BREAK
SEAWALL
SOUTH MOLE
620m
RAIL BRIDGE
DREDGING WORKS:-
BAR BLASTING
450m Wide
BAR/ROCK DREDGING
"Fremantle"
"Freeman"
Breakthrough
"Parmelia"
BASIN/SAND " "
"Premier"
"Governor"
UNDER WHARF " "
"Canning"
"Perth"
WHARVES:-
460m
1520m
1750m
Victoria Quay
305m
275m
North Mole
90m
Mail Jetty
200m
South Mole
North Quay
SLIPWAY
SIGNIFICANT EVENTS
Scheme Approval
1st Stone Tipped
Bar open
1st Vessel
1st Mail Steamer
1st Royal Mail
A.Y.U.

APPENDIX E

aim of the Department is to obtain a depth of 30 feet at low water, and with this in view it is anticipated that, the sand-movement question having been dealt with satisfactorily by the proposed breakwater-extension and the assistance of the dredger "Jupiter," the work of removing the rock from 23 feet down to 30 feet will be lightened appreciably.

In conclusion, the Author desires to thank Mr. E. M. de Burgh, M. Inst. C.E., Chief Engineer for Harbours and Water-Supply, for his permission to submit this Paper, and also for his kindly criticism and assistance during its preparation.

The Paper is accompanied by one tracing and a print, from which Plate 6 has been prepared; there are also two photographs.

(*Paper No. 3897.*)

"Fremantle Harbour-Works, Western Australia."

By Charles Stuart Russell Palmer, M. Inst. C.E.

Western Australia covers about one-third of the island continent, being demarcated politically from the rest of Australia by the 129th meridian of east longitude. On the other three sides it is bounded by the Indian and Southern Oceans. In comparison with the large area of the State, nearly 1,000,000 square miles, the coast-line is very small, being estimated at only 5,200 miles; for although the small portion north of the parallel 18° S. latitude is deeply indented, on the other hand, south of this parallel, the coast is marked by long straight reaches little broken by inlets, the only natural anchorages available, with the exception of Albany and Port Hedland, being roadsteads only partially protected.

The Harbours of Western Australia.

Responsible Government was granted to the Colony in 1889, and the great gold-discoveries of the next few years, with the resulting rapid increase of population, trade, and resources, enabled and compelled the newly enfranchised people to start extensive improvements of their estate, not the least of these being harbour facilities. These works have been prosecuted with considerable vigour, about £2,250,000 having been spent on them in the 10 years or so before 1904, in which year the Author's executive connection with the works ceased.

For the purposes of this Paper, however, attention need be directed to the marine works at Fremantle only, with some slight reference to those at Albany and Bunbury. These ports are the principal trade outlets for the area where the preponderating

settlement has taken place. The other works, distributed along the whole coast, consist of timber jetties, with their accessory tramways and other adjuncts, and have been constructed at places where the small population and trade did not warrant heavier expenditure. These jetties project, in the main, into the open roadsteads mentioned. For this reason, and also because of the great range of the tides and the violent cyclonic storms at many places, each work, though comparatively small, entailed considerable care, in order to make the most of limited means. Nevertheless, such works form a class by themselves; and although the destruction of one of the jetties in a violent cyclonic storm afforded valuable lessons, stress is laid, in the following physical descriptions, only on those features which affected the harbour-works in the south-western portion of the State.

The oldest rocks of the southern portion generally of the State are gneissic or granitoid, assumedly of archæan age, and geologists claim that this group of rocks is more largely developed there than in any other part of the world. They are greatly contorted, and, broadly speaking, now appear at the surface as four parallel belts striking roughly north and south. The third and fourth, or eastern belts, are far inland, except where they outcrop in the extreme south, and although connected so directly with the State's chief source of prosperity, the gold-mines, these belts do not require consideration here.

The second belt, which extends from the Murchison River to the south coast, forms the escarpment at the edge of the great plateau, the Darling range, the western edge of which is situated 20 to 30 miles from the coast. From this range and the inland plateau flow the rivers debouching near and at Albany, Bunbury, and Fremantle.

The first or westward belt also extends from the Murchison River to the south coast. The rocks composing it are comparatively soft, and, whether owing to denudation, attrition, or gradual submergence under the weight of superincumbent and later strata, the rocks of this belt south of the Irwin River are little exposed, except between Capes Naturaliste and Leeuwin, where they form a small range adjoining the coast. At Bunbury a basaltic outcrop and overflow forms an important headland, but the rock is apparently of a much later date than the archæan belt.

The stretch of country west of the second belt, that is, between it and the first belt or the sea-coast, consists of sandy plains, the result partly of the wearing away of the archæan rocks and of the later formations, which have evidently been greatly denuded, and

partly of seashells, including the remains of some of the minutest marine creatures. The deposits forming these sandy plains undoubtedly exhibit the characteristic false bedding of wind-blown material. Generally speaking, they have been more or less cemented below the surface into a sandstone or sandy limestone with irregular patches of purer limestone; but extensive sand-dunes, still exhibiting a tendency to travel, also occur along the western and southern coasts, at the river-mouths, or where the land is low.

Rain falling on this coastal area sinks at once into the ground, and the discharge, even of those rivers which have cut their way from the interior through the Darling ranges, is comparatively small. The many streams, therefore, that issue from these ranges do not now bring down much material, and, indeed, the volume of their waters is so small that the rivers are unable to do more than occasionally clear their mouths of extraneous sand.

In the north of the State the tidal range is large, but south of latitude 22° S. the maximum variation of water-level, and this dependent largely on the winds, rarely exceeds 5 feet, and is often a good deal less.

In the months of January and February strong currents set towards the land in the vicinity of Cape Leeuwin. The general current divides there, one part setting northward and the other part eastward along the south coast at the rate of 1 to 1½ knot per hour. Several days before, and for some time after, the arrival of the north-westerly gales, a strong set to the south is usually experienced on the west coast. Near Fremantle the current generally sets between Rottnest Island and the straggling rocks in a N.N.E. direction during the summer or with a prevalence of strong S.W. winds, and in the reverse direction during the winter or with a prevalence of strong N.W. winds, at the rate of ½ to 1½ knot per hour.

Owing to the great stretch of ocean to the west, very severe storms are possible, and the south-west corner of Australia, Cape Leeuwin, has a bad name for them; but the resulting waves have not as much effect on the shore generally as would be the case if the sandy beaches did not exist. The winds on the west coast between North-West Cape and Cape Leeuwin are generally from some southern point, mostly between S.S.W. and S.S.E. During the summer they blow almost constantly from this quarter, but their regularity is interrupted in winter by occasional winds between north and west, which at times blow with considerable violence.

The sandy country, the small flow of the rivers, and the small

range of the tides, combined with strong winds and currents, have not only deprived south-western Australia of natural harbours, but have also closed all the rivers to navigation. Thus, taking the rivers from north to south, the mouths of the Greenough and Irwin are generally closed, the Arrowsmith does not reach the sea, and the Moore is too shallow for boats of more than 6 feet draught. The Swan was blocked by a bar, and the Murray has a bar with seldom more than 6 feet of water over it. The Leschenault inlet has a shallow sand bar across the entrance with seldom water enough for a boat; the common mouth of Wonnerup inlet and Vasse estuary is often closed entirely; and the Blackwood river has a bar with 4 or 5 feet of water in summer, and 6 or 7 feet in winter and after heavy freshets.

As in the somewhat analogous case of the west coast of the United States of America, the natural forces—winds and waves, tides and currents—although acting in the same directions all along the coast, have not produced the same results at all the rivers, owing, no doubt, to differences in the trend of the coast and to the interposition of such natural features as headlands. Thus the Leschenault and Swan, being protected from the south-west, have turned their mouths, or had them forced, permanently southward; while the Murray bar, on the other hand, when cut through by freshets, forms again from the south, the mouth of the river being forced farther and farther north, until finally closed.

Moreover, there are manifest signs in places that sand-drift, travel, and accumulation are still in progress. Thus, at Hamelin Bay the sand-drift has been gradually moving eastward, maintaining apparently a height of 150 feet on its eastern side; for, a few years back, the decayed tops of karri trees, just showing through the sand, were about the same height as those not yet enclosed: and at Busselton the coast-line has been moving steadily outwards, a long length of the old timber jetty having been buried in sand to the decking. Nevertheless, the extent to which the various bays and rivers are affected by continuous sand-movement, or even whether some are not so affected, has not been easily judged in the absence of continued observations; and, as will appear farther on, it has been exceedingly difficult for responsible engineers to advise with confidence.

The Albany and Bunbury Harbours.

The Albany or Princess Royal harbour is situated in the north-west of King George Sound on the southern coast, and is almost entirely landlocked. The circumvallation consists of granite peaks

connected by ridges of sandy strata, and the entrance is narrow. Although sand-drift and travel have, in the course of time, filled the large enclosed basin, there is not now much apparent movement of the sand, nor does any river flow into the harbour.

The works necessary and carried out from time to time to accommodate the trade of the port have therefore been comparatively simple, and have chiefly comprised dredging to widen and deepen the entrance-channel, to provide a suitable anchorage-basin, and to afford access to the timber jetties; these, with their accessory goods-sheds and railway-lines, a couple of lighthouses, and some beacons, complete the works executed.

The anchorage-area is now 350 acres, with 30 feet of depth at low water, and the channel to the town jetty is 400 feet wide and 23 feet deep. There is a swinging-basin abreast of this jetty. Up to September, 1903, about 3,225,000 cubic yards of material, consisting of sand, silt, shell, and decomposed or half-formed rock had been removed and deposited at sea.

The Bunbury harbour-works consist of three main items: a lighthouse on a commanding hill, a jetty jutting out into Koombana Bay, and a protecting breakwater.

The westernmost of the archæan belts previously mentioned is still in evidence from Cape Leeuwin to Cape Naturaliste, north of which lies Geographe Bay which, as already stated, shows marked evidence of coast-advancement. To the north of this bay the continuity of the coast-line is broken by the small indentation of Koombana Bay. This has resulted from a basaltic outcrop and overflow, which, while affording protection from the south-west, left the combined mouths of the Collie and Preston rivers exposed to the lesser but still important weather from the north-west. Although these streams with their tributaries drain an area of, roughly, 2,000 square miles, having an average rainfall of 31 inches per annum, their discharge, for reasons already stated, is too small to counterbalance the effect of the sand-accumulation caused by winds and waves. The mouth of these rivers, therefore, has been gradually forced southward and now lies under the very lee of the basaltic headland, the estuary being exceedingly shallow.

The small town of Bunbury is the natural port for a large district, but, the river not being navigable, it was not possible, in the earlier days of small things, to provide more in the way of harbour facilities than a naked jetty projecting into the bay. In 1893 the head of this structure, although in only 14 feet of water, stood 2,178 feet from the shore, exposed to every weather north of due west. So soon, therefore, as the increasing volume of trade brought

about the use of coasting and other vessels of deeper draught, the question of a better-protected harbour was forcibly brought to the front, especially when actual shipwreck occurred.

The physical features of the port clearly lent themselves to the formulation of two differing harbour-schemes, and two such schemes were submitted accordingly, in September, 1896. One was for an inner harbour, and the second, which was finally adopted, was for a curved submerged breakwater, to have an ultimate length of 6,000 feet, in extension of the basaltic headland, thus forming an outer harbour. The breakwater, which was ultimately built as a visible and not as a submerged structure, consists of tipped rubble stone. Shoaling occurred in the basin and at the outer end of the breakwater, but it is hoped that a further extension will cause the latter shoal to be scoured away by natural means.

Fremantle Harbour: Locality and Preliminary Schemes.

Attention has been drawn above to the evidence of sand-drift, travel, and aggregation at Hamelin Bay, at Busselton, and at Bunbury. North of the last-named there is for about 50 miles a succession of long shallow lakes or lagoons, separated from the sea by the sand-hills or dunes before referred to. The northernmost alone of these lakes discharges into the sea, the opening being maintained by the River Murray, which in heavy freshets cuts through the sand bar at Mandurah. The bar, however, regularly forms again, the mouth of the channel being forced more and more to the north until closed.

A few miles north of Mandurah there commence two parallel lines of reefs and islands, which bear N.N.W. and terminate in Rottnest Island. The deep gulf enclosed between the chains of reefs and islands and the mainland is termed Cockburn Sound, the northern portion being Gage Roads, into which falls the Swan River through an estuary (Fig. 1, Plate 7) which is tidal for about 20 miles. Although there is marked evidence, in the spits to the east of the various islands, of previous sand-travel, there is nothing now evident to show that there is present continuous growth of spits or shore—at least in positions to which resulting inconvenience would direct attention. Nevertheless, the possibility of silting of a harbour or its entrance, whether through continuous sand-travel or through local movement to and fro, has been a source of anxiety to every engineer who has had to deal with the design of proposed harbour-works in this locality.

There is ample depth over a large area and close to the shore in the sheltered waters at the head of Cockburn Sound. There are also, between the islands, channels of approach, which are capable of improvement and even now are used by vessels of moderate draught loading timber at the Rockingham jetty. But the seaport of Fremantle, small in the days before the expansion of the colony due to the gold-discoveries, was located at the mouth of the Swan River, Perth, the capital of the State, lying 12 miles up the river; and it naturally resulted that any new harbour-work must be built in the immediate vicinity of the mouth.

All that had been achieved by 1875 was the construction of three small jetties, one in the river in 5 feet of water, and two just south of Arthur Head, in 8 and 12 feet of water respectively. The bar at the mouth of the river prevented it from being used for navigation, while any jetty advanced beyond the shelter of Arthur Head became subject to the full force of the north-westerly weather. One of the two jetties shown was so advanced and improved from time to time, but the facilities obtained were not to be compared with those of the inner harbour since constructed, and the jetty is no longer in use.

The importance of obtaining a sheltered harbour was recognized, however, even in those early days, and notwithstanding the paucity of population and revenue—indicated in the following Table—the question was entered into with vigour.

Progress of Western Australia.

Year.	Population of whole Colony.	Revenue of whole Colony.	Railways in Colony.
	No.	£	Miles.
1829	Beginning of colonization.		
1875	26,709	157,775	Nil.
1877	27,838	165,413	Nil.
1887	42,488	377,904	168
1891	53,279	497,670	203
1902	215,157	3,690,585	1,360

Fortunately for the coming port, no minor work was put in hand, and in 1877 the matter was placed before the late Sir John Coode, K.C.M.G., Past-President of The Institution, who has left it on record that the various schemes of improvement proposed up to that date might be "briefly summarized as follows:—1st, works contemplating the provision of the required accommodation elsewhere than

at Fremantle; 2nd, works for the improvement of the river lying between its debouchure and the bridge which carries the road to Perth; 3rd, external works running from the shore into deep water; 4th, open-piled jetties; 5th, solid sheltering breakwaters detached from the mainland." It is interesting to note that the germs of his own proposals, made later, are contained under the fifth heading, and those of Mr. O'Connor, made later still, under the second.

Sir John Coode made two reports; one in November, 1877, based on papers submitted to him, and the other in March, 1887, after a few weeks' stay in the Colony. His reports show that the Colonial authorities were pressing for accommodation much beyond the needs of the time, and on the other hand, as an engineer responsible to the Crown authorities, he could not have been otherwise than struck and hampered by the fact that, compared with other colonies, Western Australia had made such small progress that, 60 years after the foundation of the Colony, the population was but little over 40,000, while the revenue was so small that the interest on any considerable capital expenditure would be a serious matter.

Sir John Coode, too, had evidently been given to understand that there was decided evidence of sand-travel. Those were days before the introduction of the suction sand-dredger, and, as already mentioned, the alleged certainty, or even the risk, of large recurring expenditure could not be incurred. His proposals, it will be seen, allowed for movement of sand along the foreshore, and so far they agree with those he submitted for Timaru, in New Zealand, where the shingle-travel was the largest he had met with up to that date. There the accumulation was subsequently found to be 80,000 to 100,000 cubic yards per annum, and later on he recommended that it should be dealt with by means of dredgers.

It would have been very interesting to see how his proposals for Fremantle would have been modified after the advent of an efficient suction-dredger, after the grant of responsible Government, and after the sudden increase of population and resources which a few years brought about. Even as they stand, the proposals demand reference in detail.

Another local belief was that storms in the locality were very violent, and—what is difficult to understand, considering the coast and depths in the offing—dread in effects. The Author reads Sir John Coode's proposals as showing that he did not consider wind and wave would be severe in effect, except where the works were broadside on to the direction of the worst weather. It is also clear that Mr. O'Connor, who reported later, was of a similar opinion. Nevertheless, the belief as to the severity of the storms in this locality

persisted for many years, and forced the Government later on to incur needless expenditure in order to induce the English mail-steamers to call at Fremantle when the new harbour was in a suitable condition to receive them.

In 1877 Sir John Coode's estimate for advisable works was £242,000, and writing later of these works, he said:—

"I arrived at the conclusion that the form of work at that time best suited to fulfil the conditions of the case would consist of an open timber viaduct 1,800 feet in length, extending from Arthur Head in the direction of the Beagle Rocks, terminating with a ⅂ shaped solid pier, the two arms of which would be of the aggregate length of 1,500 feet. In addition to the foregoing, I proposed a spur jetty of 300 feet in length, to be formed at the junction of the viaduct with the solid pier, so that the total amount of berthage under this project would have been 1,800 feet in a depth of 20 to 27 feet at low water."

Reporting in 1887, after a flying visit to the State on his way home from Eastern Australia, and at a period of the year when personal observation was impossible, Sir John Coode said:—

"I had previously considered that these shoals [the Success and Parmelia banks, Fig 1, Plate 7], which are of remarkable shape, were merely accumulations of sand, and that their existence afforded strong if not conclusive evidence of sand travel to the southward and of the shoaling which would consequently result from the construction of any *solid* works extending *directly* from the shore. . . . I subsequently framed a further memorandum . . . requesting that borings might be made through the Success and Parmelia banks, in order that their character might be clearly and unmistakably ascertained. . . . From these additional particulars it is now clear that the banks referred to are accumulations of sand, and although the records of depth taken from time to time by the Admiralty authorities are not sufficiently numerous to enable their growth to be clearly traced and defined, nevertheless sufficient data are at hand to show that in all probability they are fed by the preponderating southerly movement of sand through Gage Roads and along the coast.

"Looking at the results of the supplementary borings on the Success and Parmelia banks, it would not be prudent to construct any solid structure in direct connection with the shore. To provide for the unimpeded movement of the sand, it will be requisite that any sheltering work at Fremantle should be detached from the mainland, the connection with the shore being effected by means of an open viaduct so arranged as to admit of the unrestricted passage of the sand without causing its deposition."

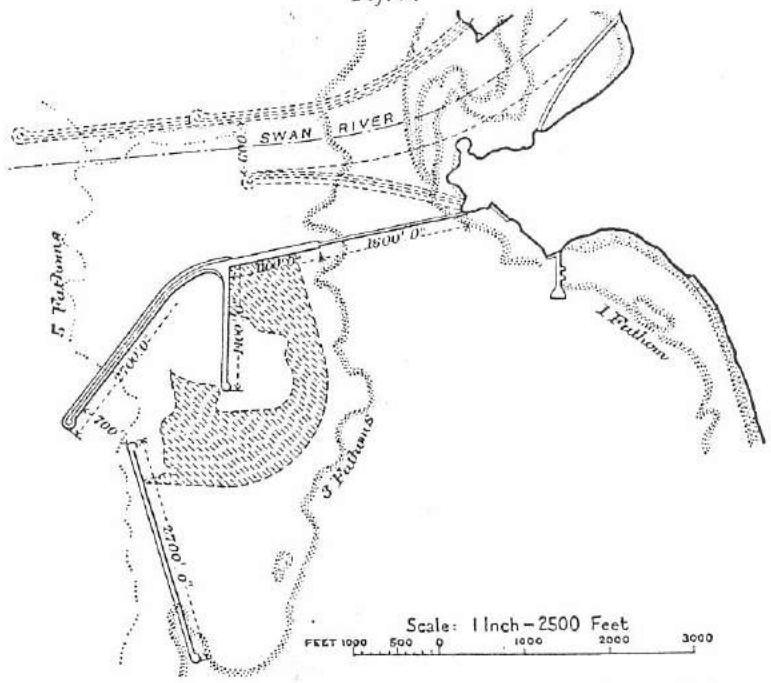
Works in Cockburn Sound being precluded, partly because of the vested interests of Perth and Fremantle, and partly owing to the alleged sand-travel, and an inner harbour in the river with an outer harbour formed by solid works connected with the shore being undesirable also on account of the alleged sand-travel, there remained only the alternative of an outer harbour connected with the shore by an open viaduct. The works of such an outer harbour would of necessity be broadside on to the worst weather.

In this connection, therefore, Sir John Coode wrote:—

"Gage Roads are open to the full stroke of the seas from N. to N.W. . . . The heaviest gales commence from N. to N.W. and travel westerly to about S.W., by which time they usually abate. These gales bring in heavy seas. . . . Whilst at Fremantle I had an opportunity of witnessing the effect upon the sea in Gage Roads of a very strong gale from the N.W. . . . This occurrence was so far fortunate as it enabled me to form a correct idea of the wave stroke that would fall on artificial works in a gale of unusual severity. . . . Having now had an opportunity of witnessing the force of the sea which would have to be encountered by these works, I am satisfied that nothing less substantial than structures of solid concrete would meet the conditions of the case in a permanent and satisfactory manner."

Sir John Coode's proposals, which, as previously stated, are of the greatest possible interest, were for works to be constructed in two successive portions. The first portion was for the accommodation

Fig. 2.



of the trade of the time and a few years ahead, carried on in ordinary trading vessels, and the second portion was for the time when larger boats, such as the Peninsular and Oriental and the Orient mail-steamers, might be expected to visit Fremantle.

The first portion of the works, estimated to cost £495,000, was to have consisted of a root or abutment with sites for offices, warehouses, etc.; an open viaduct 1,600 feet long (*Fig.* 2), carrying two

lines of railway; and a right-angled concrete pier 37 feet wide, the arms of which would have extended 1,100 feet in continuation of the viaduct and 1,400 feet at right angles thereto, in a southerly direction. Berthage to the extent of 2,500 feet was to have been formed on the lee side of the two arms of the concrete pier, in depths, after dredging (included in the estimate), of 26 feet to 29 feet at low water.

The second portion of the works was to have consisted of two sheltering breakwaters, each 2,700 feet long, to be built of riprap with a capping of concrete suitably arranged. Their cost was put at £101 per lineal foot, or a total of £545,000.

The whole cost, therefore, of the accommodation for vessels of all classes was estimated at £1,040,000.

Nothing practical, however, ensued until, some years later, the late Mr. C. Y. O'Connor, M. Inst. C.E., was appointed Engineer-in-Chief. Applying himself particularly to the question of sand-travel, he came, after much personal observation, to the conclusion, and subsequently so stated, that the information supplied to the engineers who had reported previously was in his opinion erroneous; that he could not himself find evidence of sand-travel; but that, if it did exist, it could be counteracted by dredging in the manner that Sir John Coode had recommended in the case of Timaru, where, Sir John had estimated, the expenditure of £4,000 to £6,000 per annum would overcome the evil.

Such being his conclusions regarding sand-travel, and the Colony, by now granted responsible Government, having also progressed and being mistress of her own finances, Mr. O'Connor was able to submit a more comprehensive scheme, and decided that it would be best to open up the river. There was a choice between two methods of doing this; either through the bar at the mouth of the Swan, or by means of a channel through the narrow neck of land opposite Rocky Bay (Fig. 1, Plate 7).

The latter would have permitted comparatively easy access to Perth, and a comparatively easily-dredged basin of good size for ships to lie in would have been obtained. It is interesting, therefore, to note the reasons why Mr. O'Connor did not favour the Rocky Bay channel. In a report dated the 21st December, 1891, he said:—

"With regard to the Rocky Bay scheme, it has no doubt some advantages over an entrance at the mouth of the river, as it would be somewhat cheaper to construct, and has clearer exit into bold water. The navigation, however (unless an immense amount of dredging were done), from thence to Fremantle, would be somewhat tortuous, and the project has not therefore, I think, on the whole, sufficient advantages to warrant the creation of new interests, and the sacrifice of existing ones, to which it would no doubt have a tendency.

"If the railway had not to be crossed twice, and the main road also twice, the state of the case would be materially different; but the difficulty and expense which would be entailed by these four crossings (or by deviations of road and railway sufficient to obviate them), considerably counterbalance the other advantages of the Rocky Bay entrance.

The Scheme Decided On.

Choice therefore fell on the plan of opening the bar and constructing a harbour at the mouth of the river. The scheme, approved by Parliament early in 1892, was estimated to cost £800,000 for the bare harbour, exclusive of all accessories.

Fortunately, however, the continued progress of the Colony rendered it necessary that the scheme should be enlarged, and the cost to 1903, soon after which the Author left the State, was actually £1,458,940, made up in the manner indicated on p. 180.

The harbour constructed for this sum of money is in the mouth of the Swan River at the end of Gage Roads (Fig. 3, Plate 7). A main and far-showing light, high on Rottnest Island (Fig. 1, Plate 7) indicates the locality; a second and minor one at Bathurst Point, also on this island, enables it to be safely rounded; and a third, at Woodman's Point, directs vessels along the roads until the lights on the breakwater are opened. Between the moles a channel, 30 feet deep at low water, leads to a basin of the same depth, bordered on north and south by quays.

On the south the basin is well protected naturally by high ground, but on the north the narrow neck of land, more than once threatened and once breached by the sea, has been widened out, protected on its sea face by stone revetting, and provided with an artificial breakwind. On this side of the basin, the widening and reclamation have provided a considerable area of land, and the quay is laid with railway-lines connected directly with the railway system of the State.[1] On the south side reclamation has also provided a large expanse of land behind the quay, and partly on this ground are situated the sorting-sheds for cargo, and behind them the railway sorting-yards, in direct communication with the railway goods-shed and main station.

It was the Author's ambition that the harbour should receive an increasingly valuable endowment in the shape of a line of stores and bonded warehouses situated between the sorting-sheds and sorting-yards; but the idea does not appear to have been persevered in.

[1] The plan of the harbour (Fig. 3, Plate 7) refers to 1903, and the arrangement of the railway-lines on the south side was subject to alteration later.—C. S. R. P.

The North and South Moles.

The two moles or breakwaters which flank the entrance-channel (Fig. 3, Plate 7) are of unequal importance, as from the situation of the south mole the action of the sea on it can be relatively only small. The north mole, on the contrary, protects both the harbour-entrance and its fellow breakwater from the severest weather. In Fig. 5 are shown the cross sections of the two moles. The south mole remains practically of the length originally proposed in 1892, but the north mole was extended first of all by about 500 feet to 3,450 feet in length, and then by a further 1,350 feet.

With the exception of the parapet on the north mole, both breakwaters were built entirely of tipped stone, the stones being allowed to take their own slope; end-tip trucks were used to form the leading roads, and side-tip trucks for widening out. It was proposed in 1897 that the extension of the north mole by 1,350 feet should be a submerged breakwater, but it was eventually built to full height. Also, it was feared at first that this extension of the north mole might have to be of solid concrete, on account of the probable seas; but the success of the riprap system in the older portion determined the employment of this cheaper method in the extension also.

The cross section aimed at—that is to say, the slopes to which it was anticipated the sea might eventually draw the stone out—is shown in Fig. 5; and in order that there might be material enough for the flat slopes, a parapet, as shown, was tipped to the following approximate top widths of mole: south mole, 25 feet at the root, and 40 feet at the commencement of the round head, which was given a diameter of 80 feet; north mole, 30 feet at the root, 44 feet at 2,300 feet out, 52 feet at 3,300 feet, and correspondingly wider farther out. The rounded head at the inner termination was given a diameter of 130 feet, but that at the extreme end was made only 80 feet in diameter, which the Author determined would be sufficient, in view of the fact that better stone was then being used.

The stone used in the moles was of two kinds. From the levelling down of a portion of Arthur Head and from the quarry at Rocky Bay there was obtained a material which commenced by being an arenaceous limestone, or a calcareous sandstone, with a specific gravity of 2·64, which, according to Mr. O'Connor's calculations, would have produced a mole weighing 1·23 ton per cubic yard. But, as the Rocky Bay quarry developed, the quality of the

stone deteriorated; it was found to be both lighter and considerably more friable, and recourse was had to a new quarry at Boya, some distance inland. This yielded granite of good quality with a specific gravity of 2·73.

Work on the north mole was commenced in November, 1892, with stone from Rocky Bay, and it was completed as far as the 3,450-feet mark in November, 1895. The south mole was commenced in August, 1894, with stone from the levelling down of Arthur Head, but progressed very slowly until, on cessation of work on the north mole in November, 1895, the stone-trains from Rocky Bay were diverted to it, thus enabling completion to be effected in August, 1897. The extension of the north mole was commenced in July, 1899, and completed in December, 1902.

The south mole was constructed entirely of the limestone and sandstone described, and from completion in August, 1897, until the latter part of 1902, no repairs were required. In this year, in preparation for the permanent light-tower shortly to be erected, the extreme end—which had worn and subsided slightly—and the adjacent 150 feet were topped and faced on each side with granite.

The first portion (i.e. 3,450 feet) of the north mole, including the parapet, was constructed of stone of the same class as was used for the south mole, and so also was about three-fourths of the extension. But for the outermost portion it was considered better to use granite, and in 1902 the sandstone portion was given a coating of granite on the sea face.

During construction of this mole there was considerable loss and waste of the sandstone at the tip-head in stormy weather, the work advancing very slowly in the winter months. In one bad month in 1901 there was a loss equivalent to 2 per cent. of the whole contents of the mole between the 3,450-feet and the 4,500-feet marks. But, once the stone had settled into position, little occurred. Thus, for 2 years after completion of the parapet, on the original length of 3,450 feet of the north mole, only some slight flattening of the slopes took place. During the winter of 1898, notwithstanding several severe storms, only 6 per cent. of the reserve stone in the parapet was drawn into the sea slope. The expenditure on repairs was £700 in 1898–99, and thereafter no further outlay was incurred to December, 1900. It may indeed be said that only the anticipated clawing down of the slopes by the sea occurred, and the extent even of this was moderate, as is indicated by Figs. 6, Plate 7.

Dredging.

The entrance-channel of the harbour, shown in Fig. 3, Plate 7, is 450 feet wide for a length of 3,000 feet east of the 30-foot contour, and it then gradually widens out to 575 feet in the next 1,550 feet of length, where it may be said that the basin commences. From this point the widening continues until, at a further 1,800 feet, the full basin-width of 1,400 feet is attained. This width is maintained for 2,350 feet, and the basin was designed to narrow thereafter to the railway-bridge, which is 10,000 feet east of the 30-foot contour-line.

The cutting-down of the area shown as dredged, almost all to a depth of 30 feet below extreme low water, entailed the dredging of about 10 million cubic yards of material, exclusive of the quantity above water-level which was excavated in the dry and carted into the area to be reclaimed. Of the dredgings, about 2 million cubic yards consisted of rock, and the balance of sand and silt, much of which was too compact to be worked economically with a suction dredger.

By far the larger portion of the rock to be excavated was in the entrance-channel and the adjoining portion of the basin. Here, blocking the entrance, was the bar, consisting of a long rolling ridge of rock, principally coralline limestone and sandstone, which just across the mouth of the river showed a broad crest rising to low-water level (Fig. 4, Plate 7). Of the rock about three-fourths was drilled and blasted before being removed by bucket dredgers, and of the sand and silt about 30 per cent. was excavated by bucket dredgers and the balance by suction dredgers.

The engineering problem, therefore, was twofold: first, how to bring both bucket and suction dredgers quickly to work; and, secondly, how to dispose of the dredgings economically and to advantage. To these more strictly engineering conditions was added the imperative necessity of rendering portions of the harbour available from time to time for the rapidly advancing trade of the State.

The first requirement, therefore, was to cut a channel across the bar, and drilling- and blasting-operations were commenced in July, 1894. On the 30th of the previous month the north mole tip-head stood at 2,300 feet from the land end at Rous Head, so there was sufficient shelter from the direction of the worst weather. The drilling and blasting were conducted from stages, as explained later, and successive strips 100 feet or so in width were drilled and blasted to a depth of 15 feet below low water. This depth was completed in October, 1895, and the drilling and blasting of the northern half (225 feet) of the channel followed immediately. It was effected to

the full depth of 30 feet at first and the work progressed rapidly, but complaints being received that the heavy charges necessary were damaging buildings in Fremantle, the drilling and blasting had to be carried out in two lifts, the progress being slower and the cost enhanced. When this section was completed, attention was turned to the southern half of the channel.

Some of the ground had to be gone over twice where the rock bar was exceptionally hard, so as to save the dredgers. On the other hand, in the later stages of the work, when the northern half of the channel was in constant use by incoming and outgoing vessels, drilling and blasting were dispensed with, for fear of damage to the vessels, and the dredger was kept hard up against the rock to be removed, scraping away until the channel was entirely clear.

Dredging was practically started with a bucket dredger, the "Fremantle," which arrived from England in October, 1894, and commenced work at the seaward edge of the bar on the rock already blasted. By September, 1895, a channel 200 feet wide and 12 feet deep at low water had been cut through the bar, and the "Fremantle" passed into the river. She was followed, in January, 1896, by the suction dredger "Premier," which set to work on the sand in the inner basin. To these were subsequently added a second bucket dredger and a second suction dredger, all four vessels designed by Messrs. Coode, Son and Matthews, and built, the bucket dredgers in Scotland and the others in Holland. A tug and barges were also used, for a part of the time, to hasten the progress of the work.

In May, 1897, the S.S. "Sultan," an Australian coaster, made the first passage over the bar, the channel being 180 feet wide and 20 feet deep at low water. In October, 1897, the S.S. "Cornwall," an open-sea vessel, 420 feet long and of 5,480 tons burden, berthed in the river. By July, 1899, the German mail-boats successfully used the harbour, swinging in a basin then only 650 feet in width; and in July, 1900, the dredging was sufficiently advanced for the mail-steamers of the English lines to be induced to call regularly.

Of the dredgings, a small quantity of suitable stone was deposited on the line of the north mole, and about 3 per cent. was pumped by one of the suction dredgers on to the area to be reclaimed, still leaving nearly 9½ million cubic yards to be disposed of. It was decided that the most suitable dumping-ground for the dredgers and barges was along, and not far from, the shore north of the north mole. Contours of the ocean-bed adjoining the river-mouth taken in 1897 disclosed the proximity of the 2-fathom contour to the shore north of the river. This was dangerous; for a breach, in storms, of the narrow isthmus connecting Rous Head with the mainland (Fig. 1,

Plate 7) had been threatened more than once, and had occurred once. Dumping of the dredgings was commenced, therefore, near the north mole and continued farther afield as each patch of ground was rendered too shallow for use. Ultimately the spoil was spread over an area bounded on the south by the north mole, on the west and north-west by the 3-fathom contour of 1902, on the south-east by the shore (as near, that is, as the dredgers and barges could get), and on the north-east by a line in continuation of River Street.

Of the whole quantity dredged and deposited in the years 1893–1901, namely 8,321,000 cubic yards, about 63½ per cent. remained within the area of deposition, and a further 17 per cent. was redeposited by the sea outside this area but within the limits of the soundings: of the balance, 113,000 cubic yards, or 1⅓ per cent., went to advance the foreshore, and the remaining 18 per cent. was entirely lost. An analysis of the weather-conditions in three periods from 1899 to 1901 shows that there was some correspondence between the weather and the percentage of dredgings drawn out to sea and lost to ken. These lost dredgings were not carried to the south of the harbour so far as the soundings showed, for comparison of the 1893 and 1903 contours disclosed the fact that south of the entrance-channel there had been practically no change in the ocean-bed. Even the patch south-west of the end of the south mole had remained in the same condition throughout the 10 years.

North of the north mole there have, of course, been changes, the foreshore and the 1-, 2-, 3-, 4- and 5-fathom contours all having advanced; but this, as already shown, can be ascribed to the sea having moved and distributed the dredgings. Between the surveys of 1902 and 1903 the 5-fathom contour due north of the north mole advanced markedly, and, on the other hand, the survey of 1903 also disclosed (Fig. 3, Plate 7) that the water opposite the narrow isthmus connecting Rous Head with the mainland was deepening and the foreshore was receding in this locality.

Within the harbour, however, and in the entrance-channel there had been very little silting, what there was, moreover, being counterbalanced by considerable scour in other parts of the inner basin. This area and a large portion of the entrance-channel were cleaned up between April and October, 1904, by a bucket dredger. The silt patches, also shown in Fig. 3, which formed by December, 1905, aggregated only 1,500 cubic yards, reckoning above the minimum harbour-depth of 30 feet below low water. As the sounding-line showed in the same month scour to depths of 40 feet below low water, it is probable that these silted patches are due to purely local causes.

Reclamation.

On each side of the basin was a considerable area of land which required to be cut down or filled up before it could be utilized for sheds and sidings, and early attention was given to this work of reclamation. The general levels fixed on were 10 feet above low water on the south of the harbour, and 13 feet on the north. The slopes of the earthwork were designed to extend below the timber wharves, and to have a protective facing of dry stone (Fig. 7, Plate 7) reaching down to the full depth of the basin. On the north, which was taken in hand at leisure, and where the filling consisted entirely of tipped material, the protective water face of stone was easily obtained; the stone was tipped on the top of the bank and gradually sank down, and was replaced at the top as a suction dredger excavated the basin to its full depth. The bank was coated to the bottom, and when the sloping protection had taken its set it was finished off at the top with dressed stone laid dry, in order to prevent nuisance from matter which might lie in the interstices of rough stone (Fig. 8, Plate 7).

On the south the reclamation had to be pressed forward, and the best method of construction was subordinated to a considerable extent to the exigencies of trade: also, the filling consisted partly of dredgings pumped on to the land, and partly of waste from the stone-quarry brought down in trucks. It was necessary, therefore, to provide a retaining-bank for the dredgings, with openings through which the water could drain out rapidly. The first work, consequently, was the construction of a bank from end to end, along the edge of the reclamation-area, 10 feet above water-level, and 20 feet wide. This bank had also to serve as the formation for an independent railway-line for the stone-trains from the Rocky Bay quarry to the south mole, and it was so used as soon as the railway-bridge across the Swan was completed and the north mole had reached its intermediate terminus.

The bank was faced on the harbour side with tipped stone. This would have slipped down as the dredging progressed, and a coating would easily have been obtained as on the north side of the harbour, but the work was rendered difficult, as the dredging could not be carried out fast enough for the circumstances of the case. Thus, orders were issued by the Government at the end of August, 1896, to commence wharf-construction, and by the 30th June, 1897, about 1,500 feet of quay was available for use by vessels, though the depth of water alongside was only 20 feet. By the 30th June in the following year the reclamation on the south side was completed,

and 4,450 feet of the south quay was available for use but the dredging was not complete adjoining any portion of the quay; the actual conditions were, 1,850 feet of wharf with 25 feet depth of water, 1,000 feet with 20 feet of water, and 1,600 feet with 12 to 15 feet. The result was that both the material below water and the excess stone above and below water remained badly disposed, as shown in Fig. 7, Plate 7. Matters were improved somewhat by the use of a small suction dredger to excavate under the wharf, but only part of the material could thus be moved, and it was not possible to employ a more powerful tool, for fear of damaging the ground below the sheds and a temporary passenger-station erected adjoining the quay.

The irregular disposition of the stone was not only a source of expense when the quay, constructed under pressure to accommodate traffic, was widened out to the present width, but was also a cause of serious nuisance, as the garbage which collected on the rough surface assisted in furnishing food for colonies of rats that lived in the interstices of the stonework; and these rats were a considerable source of danger in times of bubonic plague. In order to obviate these difficulties, the stonework, from the top to as low as the water would permit, was roughly "napped" to a face and coated with concrete, as shown in Fig. 9, Plate 7.

Wharfage.

The wharves or quays, which are of timber on timber-pile substructures, have an aggregate length of 9,255 feet, distributed thus (Fig. 3, Plate 7): north mole, 1,000 feet; south mole, 300 feet; jetty on the north side of the harbour, 900 feet on both sides; north quay, 2,000 feet; south or Victoria quay, 5,055 feet.

The wharves on the moles, which were built in 1897 to meet the great rush of traffic due to the rapid expansion of the State, are noteworthy because the piles of the substructure were driven into the moles, a fact which illustrates the softness of the stone and the hardness of the jarrah piles. These wharves have stood and answered their purpose well, notwithstanding the comparatively exposed position.

The jetty, which projects into the harbour from the north quay, was completed in 1900. It forms a part of the arrangements made to induce the vessels of the British-Australian mail-service to call at Fremantle, and it is a direct consequence of the mistaken ideas that prevailed in some quarters regarding the weather on this part of the Australian coast. It was feared that vessels moored against the south quay might not be able to get away safely to time in spells of bad weather. The Author believes the jetty has never

been used for the purpose it was built to serve, the mail-steamers having always found accommodation at the south quay, or having in time of bubonic plague remained at moorings in the centre of the harbour.

Of the two main wharves, that on the north of the harbour is one of the items which were designed while the Author was in immediate charge of the harbour-construction. The work in the wharf was straightforward; the piles, which are 12 feet apart from centre to centre each way, were steam-driven after the dredging was completed, and have successfully carried the loads placed on the wharf.

The history of the remaining wharf, the south or Victoria quay, in contrast to that of the other four, has been a troubled one, due partly, as previously stated, to efforts being made to provide harbour accommodation while the works were in an inchoate condition, and partly to divided counsels. Mr. O'Connor's proposals were framed to provide for easy transit inland of goods so destined, combined with as easy discharge of merchandise intended for Fremantle; while the Author hoped, by institution of free and bonded stores behind the quay, not only to assist in rendering Fremantle a great distributing-centre, but also to provide an endowment which would assist the managing authority to make of it a very cheap port indeed.

Mr. O'Connor desired the wharf and reclamation to be on the same level, with four lines of rails and hydraulic cranes on the former, to facilitate handling and distribution of cargo. As a compromise, two lines only were placed on the wharf, the cranes were dispensed with, and sorting-sheds were built on the quay, which was raised to 3 feet above reclamation-level in order to permit of easy delivery into carts conveying merchandise into Fremantle. New firms, however, not finding convenient situations in Fremantle, built their warehouses in Perth, the chief town of the State; and the older firms have had to follow the example set them. After the Author had left the State, he recommended the installation of electric cranes. These have been put in operation and have proved fully the advantage of equipping such a wharf with cranes; but the arrangements cannot be so satisfactory as if they had formed part of a complete original scheme.

In Fig. 9, Plate 7, is shown in plan the resulting quay, with its sorting- or transit-sheds existing and proposed. The westernmost 2,000 feet or so of the quay was built to 10 feet above low-water level and of the section shown in Fig. 7. It was subsequently widened. After the Author had left the State, the raising of this portion to 13 feet above low-water level was sanctioned, and a portion of it was raised. It was this 2,000 feet that was

hurriedly built, as already mentioned, to accommodate traffic; it sank to some extent, and advantage was taken during the raising to strengthen the wharf by inserting extra piles.

Minor Works.

Of the minor works, three deserve some notice, namely, the slip-way, the breakwind, and the lighthouses.

The slipway is situated at the root of the north mole (Fig. 3, Plate 7), and was intended to take vessels of a maximum dead weight of 650 tons and a maximum length of keel of 160 feet. It is a timber structure, the cradle being 185 feet long; and at ordinary spring-tides the depth of water over the keel-blocks, with the cradle at its lowest, is 10 feet 9 inches forward and 18 feet 6 inches aft. It was thus able to take any of the four dredgers used, which otherwise could not have received attention nearer than Melbourne, a good fortnight's journey, to and fro. The slip has also been of the greatest use to the smaller coasting craft.

The breakwind was erected to protect the basin from north-westerly gales, and it extends eastward from the root of the north mole for 2,200 feet along the low-lying isthmus north of the harbour (Fig. 3). It consists of quarry-refuse faced with roughly-dressed sandstone, laid dry, which is surmounted by an open picket fence consisting of 3-inch wooden uprights spaced 6 inches apart from centre to centre; the top is 45 feet above low-water level.

The five lights connected with the harbour were all obtained under the advice of Mr. W. T. Douglass, M. Inst. C.E. The main light, situated on Rottnest Island, is installed in a stone tower, and is 264 feet above sea-level at the focal plane. It is of the first order, dioptric, and with a single flash every 20 seconds. The second light, which enables Rottnest Island to be safely cleared, is situated at Bathurst Point. It is a fixed second-order dioptric light, 98 feet above low water at the focal plane. The third, or Woodman's Point light, directs vessels up Gage Roads until they open the harbour-entrance, where, at the end of each mole, there is a cast-iron tower 20 feet high, carrying a fourth-order fixed light.

There was some discussion as to the manner in which vessels should be directed up to the harbour, and at first it was proposed to erect two lights, one on Fish Rocks and the other at Woodman's Point. But it was considered that a cheaper and also better arrangement would be a single light at Woodman's Point throwing sectors of coloured light. That installed is fixed, of the first order,

and occulting, with its focal plane 126 feet above low-water level. The sectors, on the advice of Captain Russell, then Chief Harbour-Master of Western Australia, were so arranged that the westernmost or red sector can be used, if they so desire, by vessels of small draught, and the centre white portion by vessels of deeper draught, while the easternmost or green sector indicates dangerous ground.

Details of Cost.

Almost the whole of the work was carried out departmentally, and from the detailed accounts kept of expenditure and of work done the following particulars have been abstracted regarding the excavation of the channel and basin, which is divisible into two parts: first, the drilling and blasting of the rock, and secondly, the dredging.

It was essential that the drilling and blasting should be started quickly and pressed on with; to obtain special plant from Europe would have meant delay, and floating drilling-craft could not be satisfactorily employed, owing to the shallowness of the water over a large portion of the bar-crest and other parts; moreover, this rock was soft enough for the hand-drill, which was therefore employed and worked from stages. These consisted of light 30-foot planks carried on four-footed trestles with ladder-shaped tops, permitting of the planks being raised or lowered. In a couple of days 20,000 square feet of this staging could be placed in position, and it could carry 120 to 160 men, drilling with regularity in 20 feet and more of water. The holes were 8 feet to 12 feet apart, according to the quality of the rock, and the charge consisted of 12 to 15 lbs. of dynamite or gelignite, a ton of explosive sufficing for about 5,600 cubic yards of rock blasted. The expenditure on the various sub-heads of the work varied from time to time within limits, but approximately the total cost can be subdivided thus:—

	Per Cent.
Stages and other plant	16
Placing stages	6
Tugs, punts, pumping, etc.	4
Repairs to various plant	4
Stores, piping, drills and other tools	6
Explosives and blasting	16
Drilling	48
Total	100

The material dredged consisted in various parts of rock, blasted and unblasted, and of clay and sand; most of the sand was removed by the suction dredgers, but large quantites were excavated by the bucket dredgers, partly where it was too compact for removal by

the former, and partly when time pressed and it was necessary to clear particular areas quickly for commercial purposes. There were also large masses of weeds which clogged and hampered the dredgers and had to be specially dealt with. About 42 per cent. of the whole was removed by the bucket dredgers.

The whole cost of the dredging can be subdivided thus:—

	Per Cent.
Depreciation of plant	20½
Working of the dredgers	69½
Soundings, salaries of temporary staff, etc.	7½
Incidentals	2½
Total	100

The work of the bucket dredgers was too diversified for preparation of any complete subdivision of the whole cost of dredging by them; but the following Table shows the costs at Fremantle of the suction dredgers:—

—	Dredger "Governor."	Dredger "Premier."	
Period in which dredging effected	17/1/1900 to 30/3/1900	29/6/1898 to 27/6/1899	3/7/1900 to 2/7/1901
Volume removed in period Cubic yards	221,785	720,377	801,059
Time dredger delayed in period:—			
For repairs . . . Hours	135	590	408
By bad weather . . ,,	5	332	410
By other causes . . ,,	53½	76	241
Total hours delayed .	193½	998	1,069
Ratio of delays to whole working-time . . Per cent.	13	13	14
Volume dredged per hour of actual time worked Cubic yards	171	111	124
Items of Expenditure.	**Rate per Cubic Yard.**		
	Pence.	Pence.	Pence.
On salaries	0·19	0·34	0·24
,, wages of crew	1·23	1·59	1·41
,, coaling	0·08	0·10	0·08
,, watering	0·02	0·04	0·04
,, coals	0·71	0·60	0·64
,, stores	0·06	0·08	0·06
,, miscellaneous	0·16	0·18	0·23
,, repairs and renewals	0·59	1·03	0·94
,, workshops, supervision, etc.	0·14	0·28	0·19
Total	3·18	4·18	3·83

The total cost of the final scheme up to 1903 amounted to £1,458,940, distributed as follows:—

DETAILED COST OF HARBOUR-WORKS.

	£	£
North Mole:—		
To 3,450 feet—612,700 cubic yards	135,367	
From 3,450 feet to 4,800 feet—394,378 cubic yards	142,747	
South Mole:—		
To 2,040 feet—254,196 cubic yards	70,958	349,072
Wharves:—		
On North Mole, 1,000 feet long—51,285 square feet	14,419	
On South Mole, 300 feet long—14,604 square feet	4,992	
Victoria Quay, 5,077 feet long—296,136 square feet	122,686	
North Quay, 1,978 feet long—150,937 square feet	45,173	
Mail-boat jetty, 450 feet long—55,350 square feet	21,726	208,996
Reclamation:—		
North side of river—22 acres	22,865	
South side of river—54 acres	27,312	50,177
Dredging:—		
Drilling and blasting—1,503,099 cubic yards	238,345	
Dredging—9,637,501 cubic yards	455,298	693,643
Contingencies:—		
Breakwind—2,128 lineal feet	6,302	
Moorings	5,351	
Slipway, with cradle 185 feet long, for dredgers and other vessels up to 650 tons dead weight	21,644	
Office, etc.	4,566	
Land purchase	6,836	
Petty items	7,383	52,082
Total		£1,353,970

In addition expenditure has been incurred on—

Jetties in open harbour:—		
Main sea jetty	70,960	
Fremantle South	913	
Owens Anchorage, for explosives and stock	3,842	
Woodman's Point, for quarantine station	721	76,436
Lighthouses:—		
Rottnest, main	9,276	
,, eastern	3,114	
,, keepers' etc., quarters	1,619	
Woodman's Point	7,646	
South Mole	2,254	
North Mole, temporary	147	
Cable, mainland to Rottnest Island	4,478	28,534
Grand total		£1,458,940

COMMERCIAL RESULTS OF THE FREMANTLE HARBOUR-WORKS.

Recapitulating briefly the progress described in the foregoing pages, the works were commenced in November, 1892, when the first stone was tipped into the north mole; drilling and blasting of the ocean bar was started in July, 1894, reclamation on the south side of the river in August, 1895, and, under great pressure from the commercial community, the south quay was begun in August, 1896. In May, 1897, the works were sufficiently advanced for the first boat, the S.S. "Sultan," an Australian coaster, to make use of the harbour, the entrance-channel being then 180 feet wide and 20 feet deep at low tide. Finally, in August, 1900, the English mail-boat companies set their seal of approval on the works, the first vessel of these lines entering in that month. By the end of 1902 the works were so far advanced that an Act was passed constituting a Trust for management and maintenance, and this body took up its duties in January, 1903.

It is evident from this brief history of events during construction that the harbour was a great commercial necessity. This conclusion is emphasized by the facts that whereas in 1894 the whole tonnage of vessels visiting Fremantle was 337,820 tons (i.e., 406 vessels of an average net register of 832 tons), the corresponding figure in 1902 was 1,322,584 tons (657 vessels of an average of 2,013 tons), and in 1905 it was 1,462,995 tons (797 vessels of an average of 1,835 tons). This trade could not have been accommodated at all at the old outer jetty, on account of both its volume and the large size and deep draught of much of the shipping.

Financially, too, there has been a great saving, for the previous cost of handling, both from the jetty and through lighters, was excessive, whereas the charges in the new harbour are moderate, especially in view of the high wages paid in Western Australia. These charges consist, in the main, of three items: tonnage, berthage, and wharfage. The first, both inwards and outwards, is 3*d.* per ton on the registered tonnage of the ship or, alternatively, on the cargo, if this is less than one-fourth of the net registered tonnage. The berthage is 2*d.* per ton on the cargo, with a minimum of 5*s.* and a maximum of £20; and the wharfage is 2*s.* per ton on the cargo landed.

The net earnings of the harbour were £48,023 in 1903, £50,238 in 1904, and £52,511 in 1905, which on the inwards cargo only amounts to 1*s.* 4*d.* per ton. This may be contrasted with the profits of the old-established harbour of Melbourne, where the net earnings

in 1901 and 1902 averaged 1s. per ton, calculated on a fourfold volume, 2,822,000 tons, of combined inward and outward cargo. Looked at in another way, the financial results are also satisfactory, for the average interest on Western Australian Government loans was 3·41 per cent., and on this basis the annual interest on £1,353,970, the cost of the harbour-works, is £46,170 per annum, or, in round numbers, £2,000 less than the net revenue in 1903. The harbour is therefore one of economical design; moreover, at moderate expense it can be made to accommodate 50 per cent. more shipping than in 1904–5, and there does not seem any doubt that, on increase accordingly of the traffic and endowment of the harbour with storage-facilities, the port-charges could be so reduced as to lower the incidence of the net earnings from the present 1s. 4d. per ton to 8d. per ton, calculated on the inward cargo only.

It has already been pointed out that the late Mr. C. Y. O'Connor, C.M.G., M. Inst. C.E., prepared the scheme originally approved by Parliament. In addition, he controlled all alterations and took an interest in details to the time of his death in March, 1902. Of the Executive or Resident Engineers on these works at various times were Messrs. A. W. D. Bell, M. Inst. C.E., E. H. Carlin, William Leslie, J. A. MacDonald, M. Inst. C.E., G. H. Royce, and, in addition to his regular duties, the Author, who was also similarly concerned from time to time with all the other harbour-works, especially as Mr. O'Connor's successor in the position of Engineer-in-Chief of the State. Mention should also be made of Messrs. C. Good, T. C. Hodgson and J. Thompson, M. Inst. C.E., who dealt at various times as Executive Engineers with the many harbour-works of the State except Fremantle.

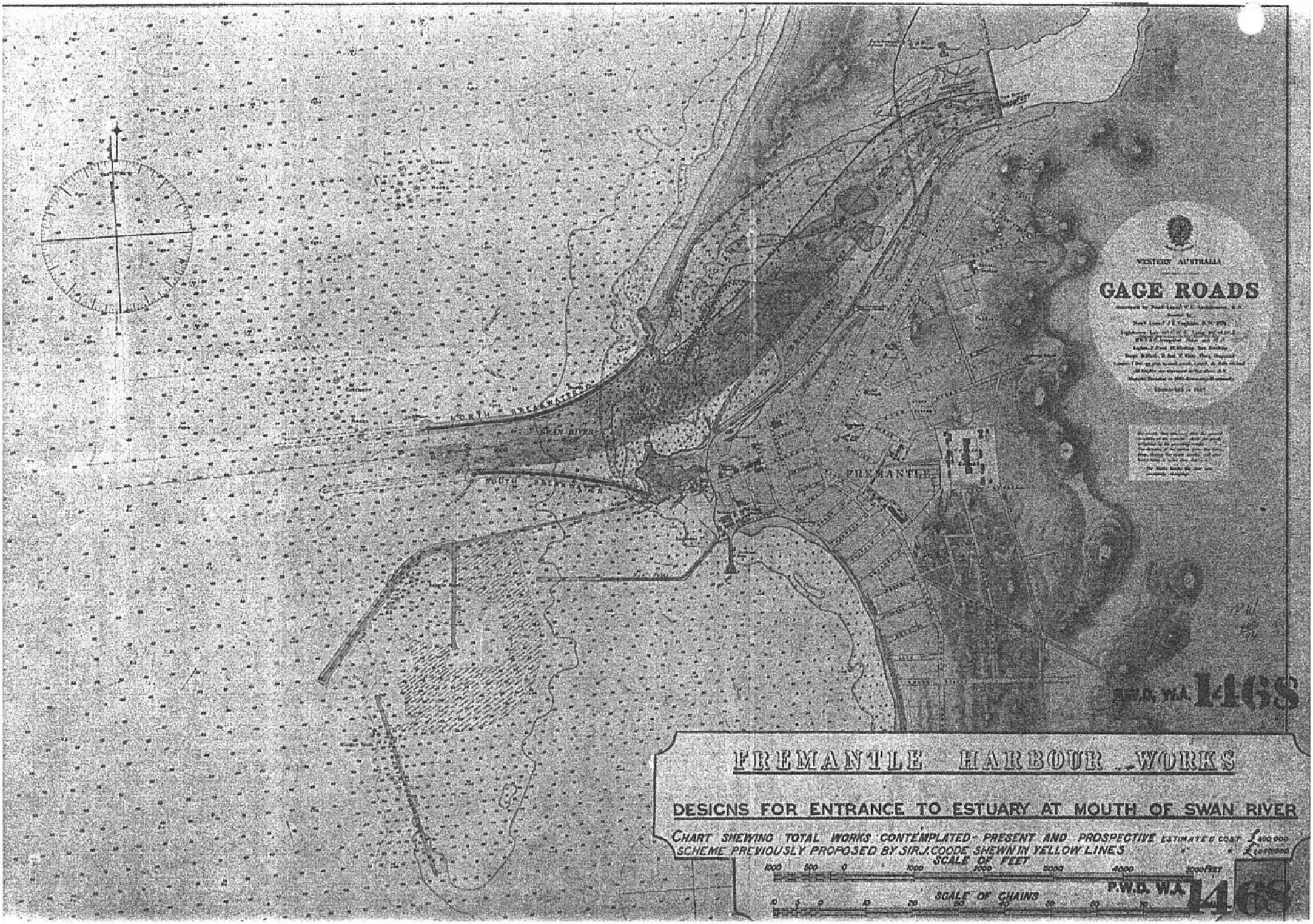
The Paper is accompanied by twenty-five sheets of drawings and maps, from which Plate 7 and the Figure in the text have been prepared.

Discussion.

The President. The PRESIDENT, in moving a vote of thanks to the Authors, observed that the members would appreciate very much the fact that important harbour-works in Australia had been brought to the notice of The Institution in three very interesting communications—Papers which showed that the conditions in Australia were quite different from, he might almost say, anywhere else.

Mr. Coghlan. Mr. T. A. COGHLAN, Agent-General for New South Wales, remarked that he was very pleased to have the opportunity of hearing three Papers read on such an important question as the treatment of harbours in Australia. He was hardly in a position to say anything as to the merits of the Papers, and therefore he could not be expected to open a discussion upon them; but he felt that they were meritorious from the point of view of the researches made and the work done by the Authors; and the question whether the ideas propounded in the Papers were good or bad would be discussed by those competent to speak upon such matters. He was very glad to see that the Authors were not unmindful of their obligation to impart to their professional brethren in other parts of the world the results of their investigations and experience in Australia. In doing this they had availed themselves of the opportunities afforded by The Institution, whose work was known wherever civilization extended; and it was a very happy circumstance that engineers in the distant dominions of the Empire were welcomed to lay before The Institution their experience and ideas, and at the same time had the full satisfaction of knowing that they were placing them before a learned and impartial body. He desired to express his appreciation of the kind reception given by the members to the Papers, and he hoped the discussion would be fruitful of ideas and corrective of misapprehensions. Some of the theories put forward —especially those in Mr. Halligan's Paper—were in a sense novel, and he trusted that the discussion would be for the benefit not only of engineers, but also of the various States in whose employment the Authors were, or had been.

Mr. Darley. Mr. CECIL W. DARLEY observed that in discussing three Papers at once it was difficult to know where to begin—and perhaps still more difficult to know where to end. In Mr. Halligan's Paper some


WESTERN AUSTRALIA
GAGE ROADS
NORTH BREAKWATER
SWAN RIVER
SOUTH BREAKWATER
FREMANTLE
P.W.D. W.A. 1468
FREMANTLE HARBOUR WORKS
DESIGNS FOR ENTRANCE TO ESTUARY AT MOUTH OF SWAN RIVER
CHART SHEWING TOTAL WORKS CONTEMPLATED - PRESENT AND PROSPECTIVE ESTIMATED COST £600,000
SCHEME PREVIOUSLY PROPOSED BY SIR J. COODE SHEWN IN YELLOW LINES " £1,000,000
SCALE OF FEET
1000 500 0 1000 2000 3000 4000 5000 FEET
SCALE OF CHAINS
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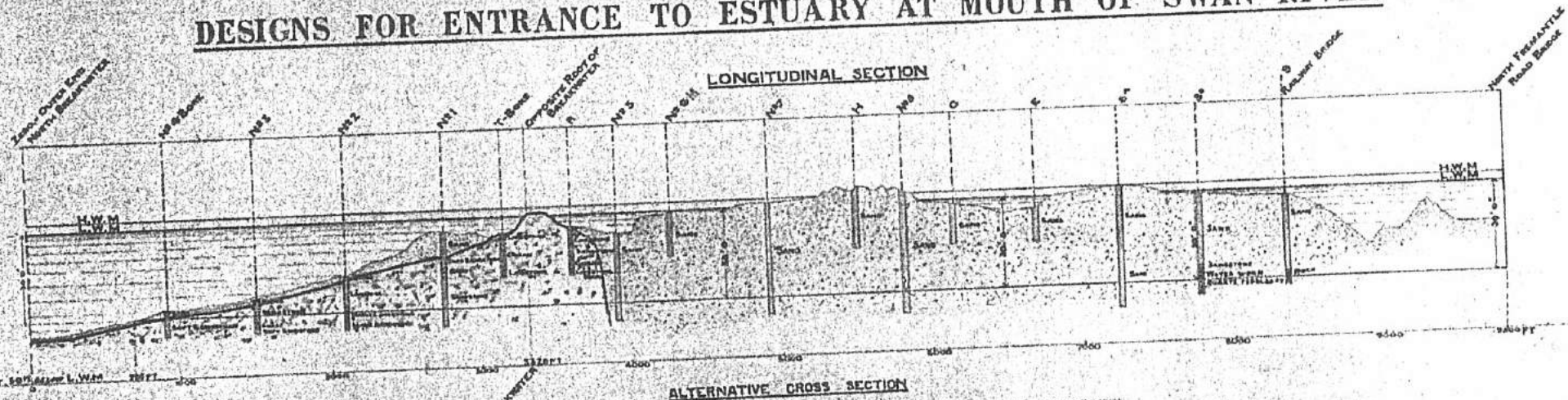
P.W.D. W.A. 1468

FREMANTLE HARBOUR WORKS

DESIGNS FOR ENTRANCE TO ESTUARY AT MOUTH OF SWAN RIVER



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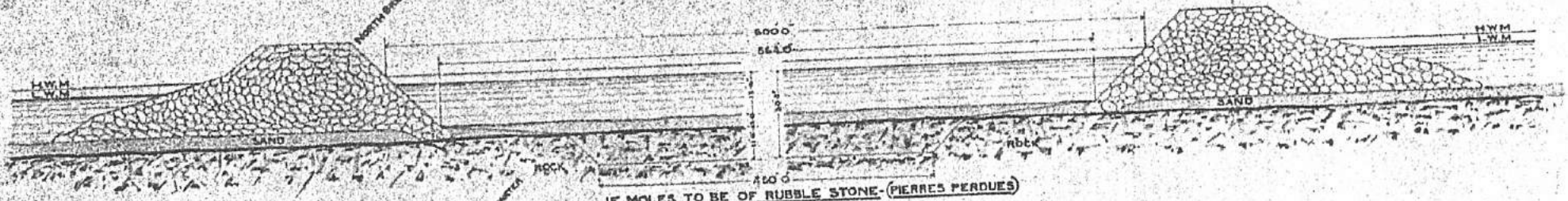
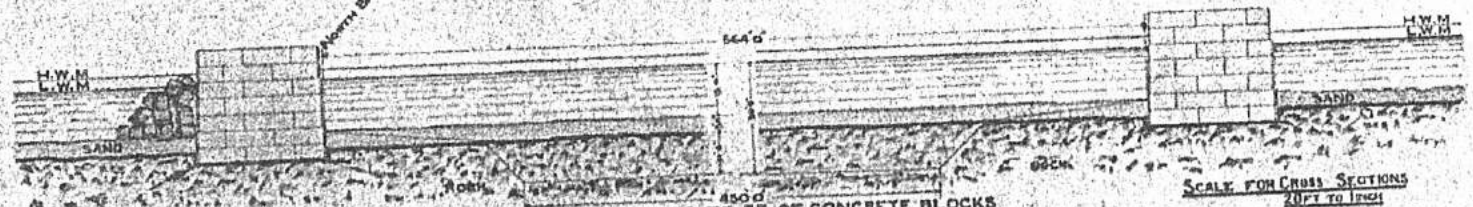


IF MOLES TO BE OF RUBBLE STONE-(PIERRES PERDUES)

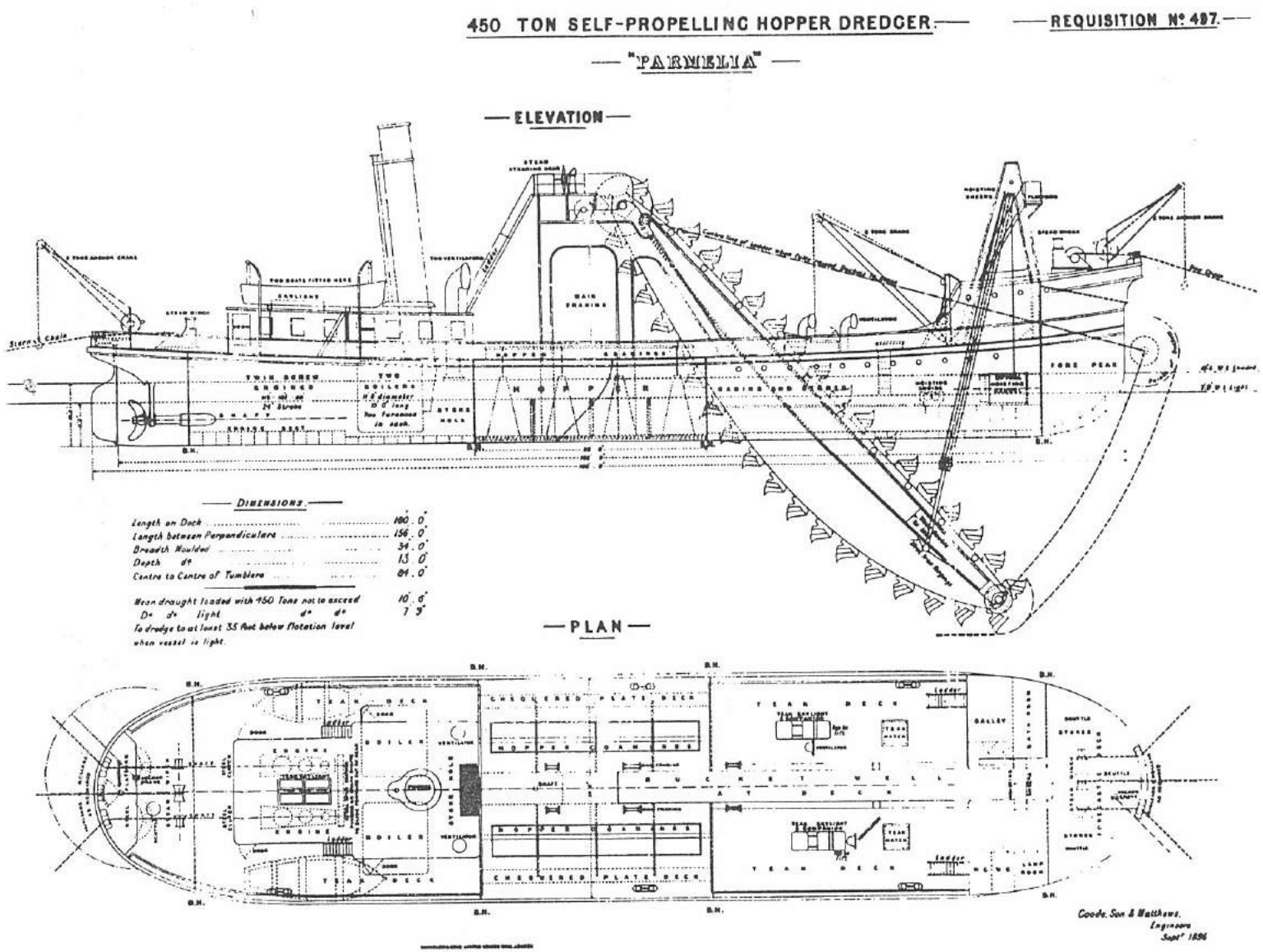


IF MOLES TO BE OF CONCRETE BLOCKS

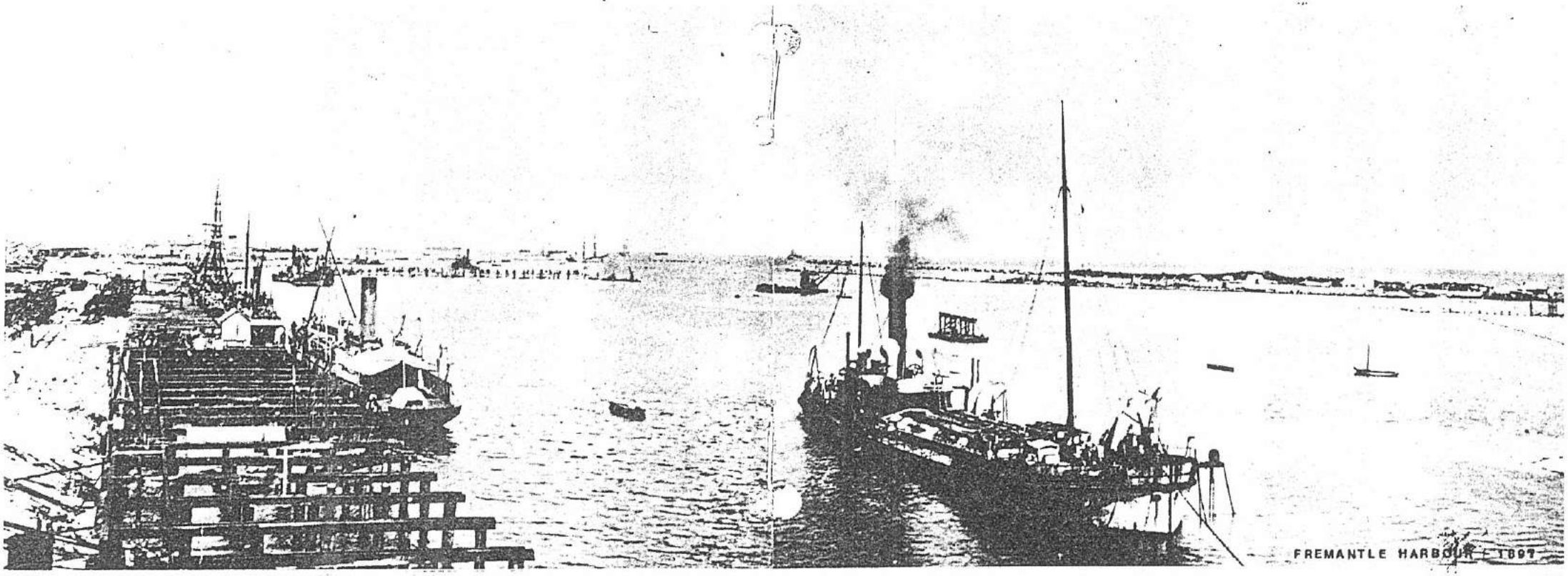
Scale for Longitudinal Section
400 FT to 1 Inch

Scale for Cross Sections
20 FT to 1 Inch

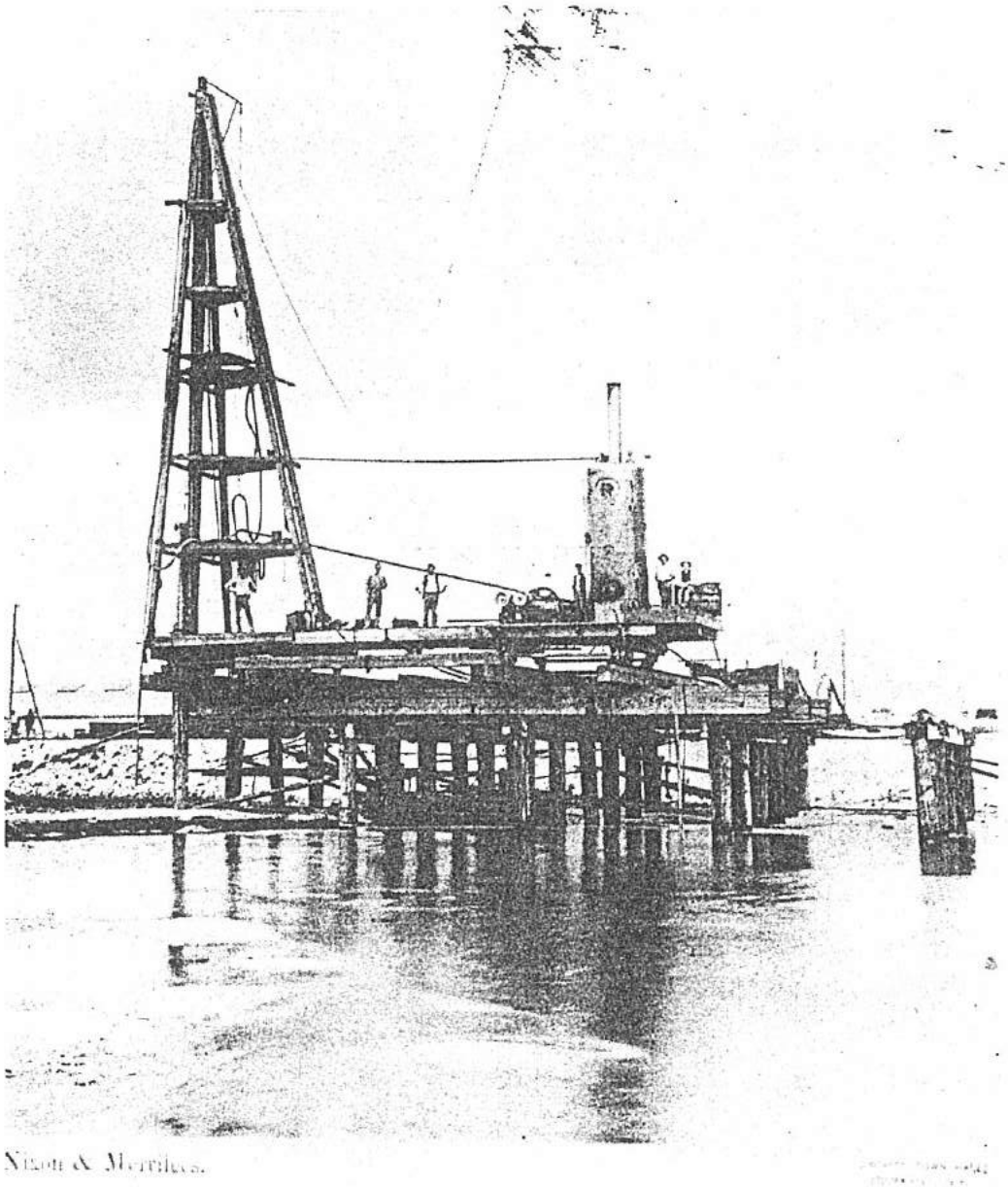
P.W.D. W.A. 1427
2



Bucket dredger *Parmelia*.



FREMANTLE HARBOUR 1899



Fremantle Harbour, pile driver, 1897.